VOL. 251 MAY 1953 No. 5

American Journal of Science

Established in 1818 by Benjamin Silliman

EDITORS
CHESTER R. LONGWELL - JOHN RODGERS

ASSOCIATE EDITORS

REGINALD A. DALY
CAMBRIDGE, MASS.

A. F. BUDDINGTON
PRINCETON, N. J.

CARL O. DUNBAR
HENRY MARGENAU
HORACE WINCHELL

RICHARD F. FLINT
HAROLD G. CASSIDY
G. EVELYN HUTCHINSON
NEW HAVEN, CONN.

LEASON H. ADAMS
WASHINGTON, D. C.

WILMOT H. BRADLEY

WILLIAM H. TWENHOFEL
ORLANDO, FLORIDA

HOWEL WILLIAMS
BERKELEY, CALIF.

FREDERICK J. ALCOCK
OTTAWA, CANADA

CECIL E. TILLEY
CAMBRIDGE, ENGLAND

GEORGE GAYLORD SIMPSON
NEW YORK, N. Y.

ADOLPH KNOPF
STANFORD, CALIF.

STERLING TOWER
NEW HAVEN, CONNECTICUT

Published monthly. Eight dollars a year. Seventy-five cents a copy.
Foreign, eight dollars sixty cents. Canada, eight dollars thirty-five cents.

AMERICAN JOURNAL OF SCIENCE

Established in 1818 by Benjamin Silliman

THE FIRST SCIENTIFIC JOURNAL IN THE UNITED STATES

DEVOTED TO THE GEOLOGICAL SCIENCES AND TO RELATED FIELDS

Editor: Chester Ray Longwell
Assistant Editor: John Rodgers
Executive Secretary: Elizabeth G. Weinman

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879. Published monthly at Sterling Tower, Yale University, New Haven, Conn.

Subscription rate $8 per year (75 cents a number). Student rate $5 per year (application blanks available on request). Postage prepaid to the United States and Central and South America; 35 cents per year to Canada; 60 cents per year elsewhere.

The Journal completed its *first* series of 50 volumes in 1845, its *second* series of 50 volumes in 1870, its *third* series of 50 volumes in 1895, its *fourth* series of 50 volumes in 1920, its *fifth* series of 36 volumes in 1938. Since 1938 the numbering by series has been discontinued, and volumes are annual and bear the whole numbers as of 1818, that for 1939 being volume 237.

Back numbers and volumes, also cumulative indices of all series, may with few exceptions be obtained from the office of the American Journal of Science, Sterling Tower, New Haven, Conn. Positive microfilm copies of each complete volume may be purchased by subscribers to the paper edition from *University Microfilms*, 313 N. First St., Ann Arbor, Michigan. Regular subscribers may purchase each past year in microcard form, from *The Microcard Foundation*, Wesleyan University, Middletown, Connecticut.

INSTRUCTIONS TO CONTRIBUTORS

Manuscripts of articles submitted should follow the recommendations in the pamphlet "Suggestions to Authors" (Lane, 1935) and should be preceded by brief abstracts. They should be checked with special care before being submitted, to avoid changes in proof other than printer's errors.

References to literature should be listed alphabetically by authors at the end of the article. All references should be complete and should comprise in order: Author's name, year of publication, full title: name of periodical or series, volume number, inclusive pages, place of publication (if needed to identify book or periodical). Except that the year should directly follow the author's name, references should follow the form given in "Suggestions to Authors" (Lane, 1935, p. 16-29). As in this example, citations within the article should be to author and year, and to specific pages if appropriate.

Plates (photographs), *figures* (line drawings), and *footnotes* should each be numbered consecutively through each article, using arabic numerals. If two photographs form one plate, they are figures 1 and 2 of that plate.

Illustrations should be neat and legible and should include explanations of symbols used. Copy that cannot be reproduced cannot be accepted. Plates and figures should be capable of reduction to not more than 4 by 7 inches, all lettering being at least 1/16th inch high after reduction. When necessary, one large map or table can be accepted, if it will not exceed 7 inches in width after reduction. Line drawings should be in black India ink on white drawing board, tracing cloth, or coordinate paper printed in blue. Photographs should be positive glossy prints. Photostatic and typewritten material cannot be accepted as copy for illustrations.

Reprints. Thirty separate copies of each article will be furnished to the author author free of cost and without previous notice from him; these will be without a cover. Additional copies will be furnished at cost, which will of course be greater if the article is accompanied by plates involving unusual expense. Copies will be furnished with a printed cover giving the title, author, volume, page, and year, when specially ordered.

Reference

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 35c.)

[American Journal of Science, Vol. 251, May 1953, Pp. 321-336]

American Journal of Science

MAY 1953

ORIGIN OF ALASKA SILTS

STEPHEN TABER

ABSTRACT. Silt, the most abundant surficial material in Alaska, is formed (1) by glacial abrasion, which is limited to a few localities, and (2) by weathering, which is widespread. It is the end product of weathering of fine-grained rocks in a climate which restricts chemical decomposition. Transportation is by water, wind, soil creep, and mud flows. Most recent investigators favor wind transportation, which the present writer regards as a minor factor.

In a few localities, such as the Delta River Valley, strong katabatic winds originating over alpine glaciers pick up dust from exposed silt bars and flood plains, but these local winds are dissipated within a short distance and the loess deposits formed are thin.

In the Fairbanks District, where glacial streams are absent, winds extremely light and dust storms unknown, silt deposits are thick because the country rock is highly susceptible to frost disintegration. The structure and composition of the silts indicate a local origin. Silts are abundant throughout Alaska because of the broad distribution of schists, slates, phyllites and shales, rocks readily disintegrated by frost.

Trunk streams transport enormous amounts of silt of mixed origin but in only a few places is dry silt exposed on bars and flood plains. Air drainage causes strong winter winds in the major valleys, and storm winds are common near the coasts, but wind transportation is restricted by the dense vegetal blanket which almost everywhere protects the silt.

The bulk of the creek-valley silt accumulated when the climate was warmer than it is now, and it was deeply frozen later. During the Pleistocene, glaciation was more extensive but in central and northern Alaska it was almost entirely confined to the mountains, and broad outwash plains were absent. Because of low temperature and light precipitation the glaciers were less active than in warmer regions. The wind pattern was probably similar to that of today and so was the protective vegetal cover.

INTRODUCTION

SILT is the commonest surface material north of the Alaska Range and other mountains extending across southern Alaska. On valley slopes and uplands it rests on bedrock, and in creek and river valleys and on coastal plains it commonly rests on older gravels that are in places auriferous. The origin of the silt has long been controversial, partly

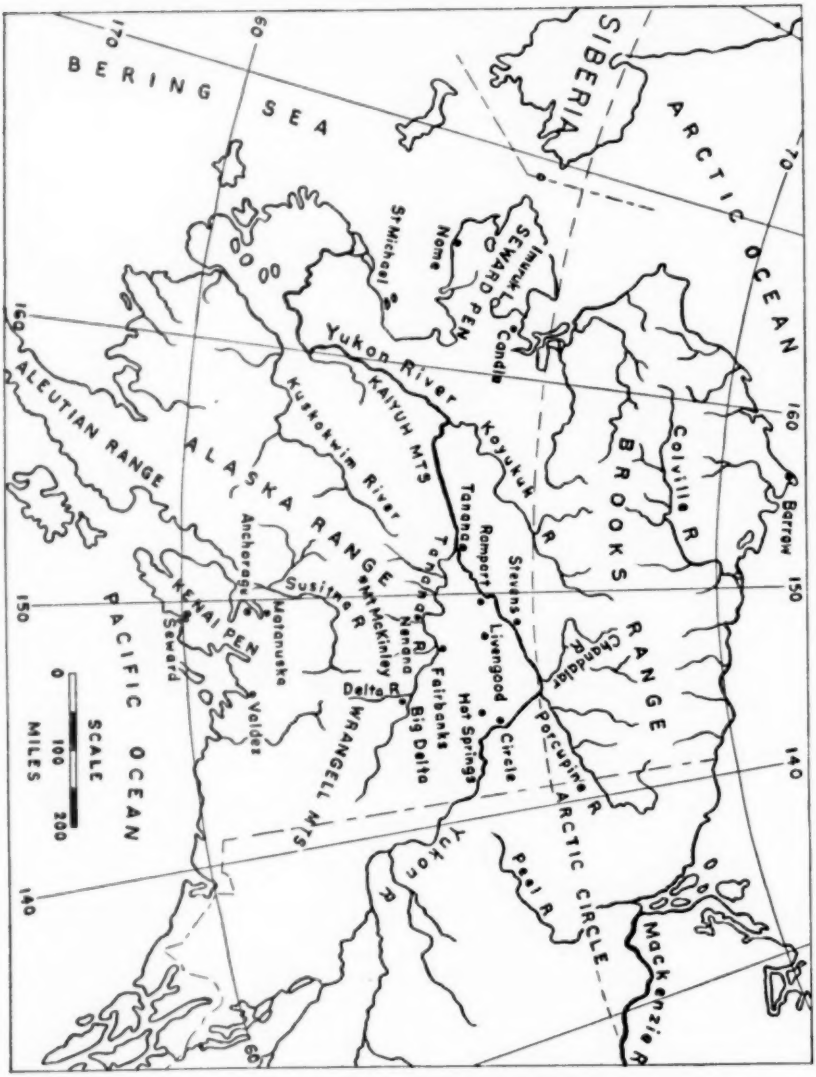


Fig. 1. Location map of Alaska

because conclusions based on evidence in a limited area may be inapplicable elsewhere. Recently most writers (Black, 1951; Eardley, 1938; Péwé, 1950 and 1951; Tuck, 1938 and 1940) have advocated a glacial origin with transportation and sorting by wind. In 1935, while studying problems related to peren-

nially frozen ground, the writer examined silts in many widely separated localities and reached the conclusion (Taber, 1943, pp. 1471-1473) that "The Alaska silts have been formed and deposited in several different ways, and some have had a very complex origin. They contain material produced by glaciation, volcanic activity, organic processes, and weathering; and the deposits may be classified as residual, aeolian, fluviatile, lacustrine, and marine." Major attention was given to the creek-valley silts in nonglaciated areas, and the hypothesis advanced to explain them (Taber, 1943, p. 1473) was that they "have been formed chiefly by disintegration of the local country rock, the products of weathering having been moved down valley slopes by soil creep and slope wash and distributed over the valley floors by occasional floods." It was also stated (Taber, 1943, p. 1479) that "During the silt accumulation transportation of fine material by wind was probably a minor factor in most places as it is today."

THE FAIRBANKS DISTRICT

Location and environment.—The silts of the Fairbanks District are typical of those found on flood plains and slopes of creek valleys over much of central Alaska and Seward Peninsula, except that they are much thicker than the average. Road cuts, water ditches and extensive mining operations have provided excellent exposures, especially in the valleys of such creeks as Cripple, Goldstream, Vault, Dome, Cleary and their tributaries. Weather observations at Fairbanks date back as far as 1904, covering a longer period than those of any station in central Alaska except Tanana which has the same years of record.

The Fairbanks District, with its rich placer mines, is located just north of Fairbanks and south of the divide between the Yukon and Tanana rivers. The area is maturely dissected with creek valleys cut several hundred feet, and river valleys about 2000 feet, below the divides. It is part of the Yukon Plateau which includes much of central Alaska drained by the Yukon River and its many tributaries. The plateau forms the upper part of the almost completely enclosed Yukon-Kuskokwim basin with the Brooks Range on the north, the highlands dividing the Peel-Mackenzie drainage from the Yukon on the east, the St. Elias Range, the Wrangell and

Nutzotin mountains and the Aleutian and Alaskan ranges, having the highest peaks in North America, on the south, and the discontinuous barrier of the Kaiyuh and Kuskokwim mountains and Kokrine Hills on the west.

Hypothesis of an exotic origin of the silts.—Péwé (1951, plate 1) recently published photographs of silt clouds in the Delta Valley and uses this phenomenon together with other evidence to support the hypothesis that the thick deposits in the Fairbanks District are aeolian in origin. He (1950, p. 65) states that "Although some of the silt may be residual, especially in areas underlain by schist, field evidence indicates that the bulk of it is eolian and was derived from glacial outwash. . . . loess is being deposited in the region today."

Taber (1943, plate 1, fig. 1 and pp. 1452 and 1500) previously published a photograph of the Delta Valley silt clouds but concluded that the winds producing them were shallow surface winds that die out within a very short distance and were incompetent to account for the thick deposits of the Fairbanks area, 100 miles and more to the north-northwest. On the day the photograph was taken the strong wind died down before reaching Big Delta, 70 miles from Fairbanks. The thinning of the dust clouds toward the north is shown in Taber's photograph and in Péwé's plate 1, B. The frequency and spectacular character of dust storms in the Delta Valley are apt to give travelers on the Valdez-Fairbanks highway through the valley an exaggerated idea of the prevalence and importance of the phenomenon.

Black (1951, p. 99), like Péwé, "favors an eolian origin for much of the original silt, recognizing that considerable movement has taken place from the hillsides to the creek bottoms . . . and that locally frost action has supplied large quantities of material that have been partly mixed with the loess."

The presence of sand dunes and loess deposits in the Delta Valley area and in other similar areas is well known, but these deposits are shallow as compared with the silts of the Fairbanks District which have a maximum thickness of over 200 feet. Christ (1951, pp. 148-149) contrasts "the shallow silt profile that overlies the gravels of the Kenai Peninsula, the Matanuska and Susitna Valleys, and the Delta Valley of the middle Tanana region, [with] . . . the depth of the silt

deposits in the Fairbanks section. . . . Winds of high velocity whip up the glacial flour from the annual deposits along the bars of streams. None of the land so built has a great enough depth to warrant having it exposed by ill-considered farming methods."

The area of silt in Delta Valley not protected from the wind by vegetation is extremely small, being confined to the bars of a short braided river, and only a minor fraction of this silt is removed by wind to be deposited elsewhere, because most of it is gradually carried downstream by the river.

Delta Valley dust clouds, especially in summer, seem to be caused by local katabatic winds. Alpine glaciers occupying tributary valleys on both sides of the river reflect much more of the sun's energy than does the surrounding land surface. Air in contact with the ice becomes colder than the surrounding air and consequently flows rapidly down the steep slopes of the glaciers to form a strong air current in the narrow Delta Valley, but the shallow current thus generated is quickly dissipated by turbulence and by spreading when it reaches the broad Tanana Valley. Occasional high winds induced by a strong barometric gradient blow through Isabella Pass and down Delta Valley but are likewise largely dissipated after reaching the Tanana Valley.

D. J. Stowell, Official in Charge, U. S. Weather Bureau Station at Fairbanks, suggests[1] that the "Isabella Pass" or Delta Valley wind and the somewhat similar wind in the Tanana Valley "are primarily due to enforced concentration of streamlines in narrow valleys and to the Bernoulli effect. . . . Your statement that winds originate on the glaciers tributary to the Delta River is very interesting. This effect probably accounts for most of the gravity component of these winds and does much to explain why they are nearly as strong in summer as in winter. . . . This [Delta Valley] wind is extremely gusty, with gusts frequently reaching twice the average wind velocity which may be as high as 40 to 45 miles per hour. This wind is strictly local and never reaches any other station. . . . Neither the wind nor the dust cloud has ever been reported at Fairbanks.

"The Tanana Valley wind blows from the east-southeast at Big Delta. It is more constant in both direction and velocity

[1] Letter dated February 8, 1951.

than the Isabella Pass wind and is usually not so strong. It seldom raises the snow or dust. This wind is more widespread. It blows from the east-northeast at Nenana with only slightly lower velocity than at Big Delta. Other stations in the Tanana Valley, including Fairbanks, sometimes report this wind but always with a lower velocity."

The Tanana River is a braided stream with numerous silt bars from above Big Delta to the vicinity of Fairbanks, but apparently the winds are seldom strong enough to pick up silt in this area. Higher up the valley, nearer the glaciers that feed tributary streams, the wind is probably stronger.

Since the Delta Valley katabatic wind is not ordinarily accompanied by rain, it is relatively efficient in removing silt from river bars during the short summer when the silt is not covered with snow and ice.

In summer a weak low pressure area is usually present over the Yukon Plateau so that local factors are important in the development of winds, but in winter a high pressure area prevails over the plateau and this together with the Aleutian low over the North Pacific and the storms originating there largely control the winds. The lofty Alaska Range protects the interior from the numerous storms developing in the area of the Aleutian low, and the severest storms along the Pacific Coast (Frost, 1934, p. 271) have little effect on the plateau other than a rise in temperature in winter. A few storms entering Bering Sea move up the Yukon Valley but they are partly obstructed by the Kaiyuh and other mountains between the sea and the interior. According to C. J. Champion, Jr.,[2] the strongest winds at Fairbanks blow from the southwest in connection with these storms which occur mostly in the late winter and early spring. They do not cause dust storms. The Brooks Range protects interior Alaska from winds that blow from over the Arctic Ocean.

In winter cold air from over the plateau and enclosing mountain slopes drains down river valleys causing strong winds, especially where there are constrictions in the valleys as at the rapids near Rampart on the Yukon and near Hot Springs on

[2] Oral communication, February 1951. Mr. Champion was then stationed at the Fairbanks Weather Bureau Station and was later transferred to the Nome Station.

the Tanana. These are also katabatic winds but they are not strictly local as are the summer winds in the Delta Valley.

Above Rampart, between Stevens and Circle, the Yukon broadens to form a braided stream ranging up to 15 miles in width. This area of deposition, known as "The Flats," is not due to local overloading but to a change in the profile of the stream. The nearest glaciers feeding the Yukon are in the headwaters of the White River, nearly 500 miles upstream, and in this distance much sediment of nonglacial origin is picked up by the river. Much of this large area is swampy but considerable silt is picked up by wind from bars unprotected by vegetation. No dust clouds were seen when the area was visited by the writer, but according to local observers occasional dust clouds extend downstream though they do not spread out far from the river. They are not reported from Circle Hot Springs or Livengood. No dust is now being carried from the Yukon into the creek valleys of the Fairbanks District.

In describing winds at Fairbanks, Frost (1934, pp. 276-277) states: "Perhaps the most striking peculiarity of the climate is the total lack of wind for long periods during the winter months. January, the month with least wind movement, has an average of 323 hours of calm. The greatest number of consecutive hours is 51, in 1934. In January 1934 there occurred a period of 82 hours during which but 1 mile of wind was recorded. The hours of calm in January 1933 numbered 399, which is 54 percent of the total hours in the month. The highest velocity ever recorded at Fairbanks since the automatic recorder was installed was 32 miles per hour on May 12, 1934. . . . The mean annual velocity at Fairbanks is 3.8 miles per hour." The deeply cut valleys of the Fairbanks mining district must have even less wind than at Fairbanks, as they are relatively short and do not serve as drainage channels for cold air from over glaciers in summer or from extensive highlands in winter.

In a large area surrounding the Fairbanks District a dense cover of peat and vegetation protects the surface from erosion by wind or water except for the very limited exposures of silt on river flood plains and bars and the rocky mountain slopes where almost no fine material is available for wind transportation. All available evidence indicates that the thick silt deposits of the Fairbanks District are not now being augmented by material from the outside other than the minute amounts of

dust, and of volcanic ash from distant eruptions, carried by upper air currents.

At the time of maximum glaciation the topography of the Fairbanks District was essentially the same as it is now. Elsewhere in Alaska the Pacific Cordillera was, in places at least, a little lower than it is today and the coastal areas were possibly larger, especially in the shallow water areas of Bering Sea and the Arctic Ocean. Glaciers came down into the Delta Valley and extended beyond the base of the mountains, reaching a point about 100 miles from the Fairbanks District, and some glaciers on the flanks of Mt. Hayes and Mt. Hess came even closer, but they were still essentially valley glaciers. Because of lower temperature and less precipitation than at present and gentler slopes near the foot of the mountains, the glaciers were not very active, and, individually, probably produced less silt than they do today, but they were more numerous. Streams were smaller because precipitation was less and was in part retained to augment glaciers. During glacial recession streams were larger, but broad outwash plains, such as were present on the Pacific side of the Cordilleras and in the Mississippi Valley area, were absent. Several small glaciers were present on the divide between the Yukon and Tanana in the vicinity of the Fairbanks District, but they occupied valleys not tributary to creeks in the district and they were too small to influence the winds.

The Aleutian low was more nearly permanent during maximum glaciation than it is today and the intensified North American high prevailed in summer as well as winter, making it more difficult for cyclonic storms to invade central Alaska. This together with lower temperatures reduced precipitation.

Under these conditions the Delta Valley wind was a little stronger and the dust clouds reached a little closer to Fairbanks than they do now, but the difference would be insignificant. Air drainage down the Yukon and Tanana valleys was probably somewhat intensified, but the wind pattern was the same as now so that aeolian silt did not reach the creek valleys of the mining district. The mean annual temperature was about like that of northern Alaska today but with warmer summers and cooler winters because of the greater temperature range in the interior. The summer temperature was probably not quite high enough for evergreen forests, but the ground was

covered with dense tundra vegetation which protected the soil from the wind as it does today over most of central and northern Alaska.

The evidence now available, therefore, indicates that the formation and transportation of glacial silt in the vicinity of the Fairbanks District did not differ appreciably during maximum glaciation from that of today, and that this silt was not carried into the creek valleys of the district. Additional evidence bearing on the origin of the silts is revealed by a study of the geological history of the creek-valley deposits.

Hypothesis of a local origin of silts.—Field and laboratory studies in the Fairbanks District indicate a local origin for the silts. They do not decrease in thickness or in grain size with distance from glacial streams. Nowhere do they show the vertical structure characteristic of loess; on the upper slopes they are structureless and in flood plain deposits they are well bedded. In neighboring creek valleys they differ in their mineral and chemical composition. No air sorting has resulted from differences in density, size or shape of mineral grains. Heavy minerals such as garnet, ilmenite, magnetite, rutile and zircon are found associated with much quartz and even muscovite, in the bedded silts and in silts from valley slopes 305 feet above Goldstream Creek and 375 feet above Dome Creek (Taber, 1943, pp. 1476-1478). Angular fragments, chiefly vein quartz and micaceous quartzite, ranging up to several inches in diameter, are present in both the bedded and non-bedded silts.

The dominant rock types in the Fairbanks District are fine-grained schists and slates, rocks peculiarly susceptible to disintegration by frost action, though even basaltic rocks may be reduced to silt in climates where chemical weathering is largely inhibited by low temperature. On Candle Creek near the Arctic coast of Seward Peninsula a large surface of slightly weathered slate, exposed for only one year, disintegrated to a depth of 2 or 3 inches as a result of freezing and thawing to form a fine silt, some of which retained the structure of the slate but crumbled when touched. On St. Michael Island silts derived in part from volcanic breccia contain less silica and more calcium and magnesium than silts in areas of schistose rocks (Taber, 1943, p. 1480). In the Imuruk Lake area, Seward Peninsula, which is largely covered by Quaternary basaltic

flows, Hopkins (1949, p. 121) found that frost riving was the chief factor in weathering, the end product being a "rather uniform material in the silt range." The youngest flows extruded within the last two or three thousand years have 1-6 inches of silty or sandy soil in protected hollows and crevices; the oldest and most widespread flows, exposed to frost riving throughout much of the Pleistocene, are mantled with 5-20 feet of uniform, fine-grained residual soil.

Formation of silts by frost action is not as spectacular as the glacial rock-mill, and, therefore, has been largely overlooked. Silt is the end product of weathering where a cold climate favors mechanical disintegration and retards chemical weathering with the formation of clay minerals. Accumulation of very thick valley silts is dependent on a high frequency of the freezing cycle at the surface of the country rock when water is present, and this necessitates removal of silt from slopes before it becomes so thick as to inhibit freezing and thawing. Today in the Fairbanks District downslope migration of silt is largely prevented by the vegetal cover and frozen subsoil. Therefore, very little or no silt is now being added to the valley deposits.

The Quaternary history as recorded in the creek-valley deposits, so beautifully exposed in the placer mines, clearly reveals that the silts accumulated when the climate was warmer than it is now and that the ground was not perennially frozen until later, presumably during the first glacial stage. The main events in the geological history as described by Taber (1943, pp. 1529-1541) are listed below:

1. Deep weathering in a region of low relief with residual concentration of gold.

2. Rejuvenation of streams by uplift, erosion of soil mantle, and concentration of gold in stream beds.

3. Simultaneously, or a little later, a broad extension of coastal areas permitting intercontinental and interisland migration of Pleistocene mammals. The enlarged land area would increase aridity in central Alaska.

4. Deposition of thick deposits of unsorted angular to subangular gravel suggestive of aridity.

5. Abrupt change from gravel to silt deposition, probably due to greater humidity resulting from submersion of extensive

coastal plains and to reduction of evaporation by lower temperature. Distribution of flora and fauna indicate a climate slightly warmer than at present, but not cold enough for perennially frozen ground. A dense vegetal cover retained rock waste on slopes until most of it was thoroughly disintegrated. Distribution of silt by occasional floods buried turf on flood plains and killed trees, leaving the stumps in place.

6. Increasing cold resulted in freezing to depths of 300 feet or more with the formation of segregated ice that, in favorable places, makes up as much as 75 per cent of the mass by volume. The ice is mostly in the form of layers or lenses and of wedge-shaped veins that curve into layers where the latter have not been removed by thawing and erosion. Veins extend to depths of 100 feet below the surface and, perhaps, 150 feet below the surface at the time the ground was being frozen. The veins do not transect ice layers, as would be necessary if formed after the freezing of the silt, as advocated by Leffingwell (1919, p. 242) and others for similar veins in the Arctic Coastal Plain.

7. Subsequently, during at least one period, presumably an interglacial stage, the climate was warm enough to cause deep thawing. Meltwater from ground ice was added to precipitation to cause mud flows on slopes and rapid erosion on slopes and flood plains wherever the turf was broken, for the thawed silt contains almost no clay or other binder. In some places silt was deposited on the eroded surface of the older silt.

8. Change to a colder climate resulted in refreezing of thawed silt not removed by erosion, and the freezing of the younger silt. Only a few small lenses of ice were formed during the last freezing because water could not be supplied through the underlying frozen ground. No appreciable deposition or erosion of silt has occurred since the refreeze.

All of the evidence obtained in this investigation indicates that the creek-valley silts of the Fairbanks District are of local origin, and that no appreciable amount of wind-borne glacial silt is now being brought into the district or was brought in during the Pleistocene. The exceptional thickness of the silts is due to the peculiar susceptibility of the prevailing country rock to disintegration by frost action.

SILTS OUTSIDE THE FAIRBANKS DISTRICT

In many creek valleys of central Alaska and Seward Peninsula the geological history, with minor variations, has been essentially the same as in the Fairbanks District. In addition to the silts on slopes and in creek valleys, silts of mixed origin are present in enormous quantities in the valleys and deltas of the larger streams and on some coastal plains. The Yukon and Kuskokwim have built one of the largest of known deltas. Glaciation has been active in a few limited localities but mechanical weathering has been widespread.

Glaciation in Alaska today is almost entirely limited to the mountains of the Pacific Cordillera. Many glaciers, including several large piedmont glaciers, are present in the area of high precipitation on the south side of the divide separating Pacific drainage from drainage into the interior, but on the more arid north side only a few relatively small valley glaciers are found. Also, because of lower temperature as well as less precipitation, glaciers are less active on the north side of the divide. Therefore the amount of glacial silt supplied to the Yukon-Kuskokwim basin is very small as compared with that carried toward the Pacific.

During the Pleistocene most of the alpine glaciers north of the divide, as shown on Capps' (1932, plate 1) map, extended to the base of the mountains, and they were more numerous, but the map exaggerates the amount of glaciation, for the boundary lines are drawn to include all glaciated areas rather than to exclude nonglaciated areas. Valley glaciers may have coalesced in places to form small piedmont glaciers but there were no broad ice fronts with extensive outwash plains such as those on the south side of the divide or along the southern front of the continental ice sheets. The small expansion of Pleistocene glaciation on the north side of the divide when temperature was lower than it is now can be explained only by less precipitation.

Capps' map shows a large area covered by ice in the southern part of the Seward Peninsula with a tongue 10 miles wide extending to the Coast at Nome. The only evidence, known to the writer, for such a tongue is a few striated boulders encountered in mining the coastal plain gravels, but the presence of rock monuments, such as those in the Snake River Valley on the lower slopes of Mt. Brynteson, and Anvil Rock near

the base of Anvil Peak indicates that only small glaciers could have been present in the valleys of the Snake and Nome rivers.

Because of aridity, glaciers are now absent in northern Alaska except for a few very small ones in the Brooks Range. Barrow on the Arctic Coast has an annual precipitation of only 4.74 inches, and precipitation was even less during the time of maximum Pleistocene glaciation. It is probable that detailed studies will show that glaciation in the Brooks Range was largely confined to valley glaciers and small inactive ice caps and did not blanket the large area shown on the map. Because of low temperature and precipitation these glaciers must have been relatively inactive, and, therefore, they were only a minor factor in supplying silt to the Yukon and other rivers.

Frost riving is a major factor in rock weathering in central and northern Alaska, but susceptibility to disintegration varies greatly with different rocks. Field observations and experiments by the writer show that fine-grained cleavable rocks are, in general, most vulnerable, while coarse-grained and massive rocks are most resistant.

The Precambrian Birch Creek schist of the Fairbanks District extends over an area of more than 20,000 square miles in the Yukon-Tanana area. Quartzite, the most resistant rock in the formation, is commonly exposed in bold outcrops while less resistant rocks are masked by silt and vegetation. The best indication of the relative abundance of the different rock types is furnished by the creek-valley gravels which consist chiefly of fine-grained mica schist, phyllite and slate, though chlorite and hornblende schists and micaceous quartzite are common. Also the fine-grained cleavable rocks suffer more loss during transportation.

The geological map of Alaska (Smith, 1939, plate 1) shows large areas of undifferentiated metamorphosed sedimentary rocks, Paleozoic or older in age, on Seward Peninsula and in the drainage basins of the major rivers of central Alaska. Also many rock formations mapped under the various divisions of the Paleozoic and Mesozoic contain schists, slates and phyllites as well as shales. Easily disintegrated shales are common where the rocks have not been metamorphosed, although the resistant limestones and sandstones are much more conspicuous.

Transportation of silt by rivers is greatest during spring thaws and was at a maximum during the warm interglacial stages when meltwater from ground ice as well as from shrinking glaciers was added to the normal precipitation. Large fluctuations in stream flow tend to increase the areas of silt exposed to wind action during periods of low water, but snow and ice partly protect the silt from winter winds.

Storm winds are largely confined to the Arctic slope and the coasts, but Frost (1934, p. 276) reports strong winds resulting from air drainage along rivers descending from the Endicott Mountains in the Brooks Range as well as along the Yukon and Tanana rivers. Winds are often strong on high divides, especially in the cols, but in these localities there is little fine rock waste available for wind transportation. During maximum glaciation winds of local origin must have been much the same as they are today, perhaps a little stronger in some places; but the planetary circulation in this region was probably weaker rather than stronger, for the difference in temperature between the Arctic and mid-latitudes was less while the difference in temperature between mid-latitudes and the equator was greater.[3]

Although silt is the major soil component in central and northern Alaska, and the winds at many places are strong enough to transport it, very little silt is moved by wind because of the widespread vegetal cover. Most low-lying areas are forested, except coastal regions, the Arctic slope and most of the Seward Peninsula; and the dense mat of low-growing plants on the forest floor extends above the tree line and over most of the unforested areas. The mat of living plants grades downward into a layer of peat, ranging in thickness from a few inches to more than 10 feet (Taber, 1943, pp. 1444-1446 and plates 1-4), which protects the silts from deep thawing in summer. The density and thickness of this blanket is amazing to one unfamiliar with the northern tundra where plant growth is luxuriant during the long periods of summer sunlight, and much of it is preserved as peat because low temperatures restrict bacterial decay. A perennially frozen subsoil prevents subsurface drainage, and the peat holds water like a sponge. The blanket is broken occasionally by freezing and thawing (Taber, 1943, fig. 5), overturning of trees and other

[3] The climate during maximum glaciation is discussed in another paper to be published shortly.

causes, but the ground exposed is usually wet. In the far north the vegetal cover is thinner, because of lower temperature and greater aridity, so that it is more easily broken and more bare soil is exposed.

The cover is absent along sea beaches and, in a few places, on river bars and flood plains; and it is in these localities, according to Black's (1951, fig. 1) map of aeolian deposits, that sand dunes, and to a lesser extent, loess deposits are concentrated. However, some of the large areas mapped as loess, such as the one in the vicinity of Fairbanks, are not, in the writer's opinion, buried under aeolian silts.

Sea beaches are narrow at most places, for the sea is encroaching on the land, and, therefore, on vegetation. This probably explains why the coastal dunes are relatively small. Along the Carolina coast old tree-covered dunes, formed when the sea was receding, are much larger than those forming now where the sea is encroaching on forests. However, the largest dunes along that coast, 100 feet or more in height, are now forming where the forest was cleared from large areas and the land used for grazing. (One such dune is Kill Devil Hill, made famous by the Wright brothers.)

The Arctic slope is more favorable for aeolian erosion because of stronger winds and, on the average, somewhat thinner vegetal cover, but areas bare of vegetation are not large and sand dunes are small. Black (1951, pp. 92-97) reports many dunes, active and stabilized, and also some loess, especially along the lower Colville which is here a braided stream. Leffingwell (1919, pp. 155, 156, 163, 175 and 202) describes horizontally bedded silts in river banks and deltas and even silt dunes, but states that most of these dunes are confined to the immediate banks of rivers, the silt having been derived from the mud flats of rivers. He observed discolored snowdrifts about 5 miles in the lee of a silt-dune area but concludes that the amount of silt transported more than a few hundred yards is very small, for there are unburied boulders which must have been upon the surface of the tundra a very long time. The rivers of the Arctic slope are not fed by glaciers.

During maximum glaciation trees probably disappeared from central Alaska except, possibly, on the sunny slopes of protected valleys in the Yukon Plateau, where a few stunted spruce may have survived. The vegetal cover was thinner on the Arctic slope so that a little more silt could be moved by wind, but

in the rest of Alaska the ground was about as well protected from wind erosion as it is now.

CONCLUSIONS

Wind-borne glacial silts are important in a few limited areas, but silts formed by frost disintegration of fine-grained cleavable rocks are widely distributed. In the Fairbanks District, which is typical of a large area, silt deposits are thick though glacial streams are absent, winds extremely light and dust storms unknown. The dense vegetal blanket, almost universally present, is a major factor in restricting wind transportation.

Black and Péwé favor an aeolian origin for the silts but admit that frost disintegration is a factor. The difference between their conclusions and those of the writer is one of degree rather than kind. In view of the long controversy over the origin of Mississippi Valley loess, early agreement on Alaska silts is not to be expected.

REFERENCES

Black, R. F., 1951. Eolian deposits of Alaska: Arctic, vol. 4, pp. 89-111.

Capps, S. R., 1932. Glaciation in Alaska: U. S. Geol. Survey Prof. Paper 170.

Christ, J. H., 1951. Farming in the land of the midnight sun: Soil Conservation, vol. 16, pp. 147-149 and 152.

Eardley, A. J., 1938. Unconsolidated sediments and topographic features of the lower Yukon Valley: Geol. Soc. America Bull., vol. 49, pp. 303-341.

Frost, R. L., 1934. A climatological review of the Alaska-Yukon Plateau: Monthly Weather Rev., vol. 62, pp. 269-280.

Hopkins, D. M., 1949. Thaw lakes and thaw sinks in the Imuruk Lake area, Seward Peninsula, Alaska: Jour. Geology, vol. 57, pp. 119-131.

Leffingwell, E. De K., 1919. The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109.

Péwé, T. L., 1950. Origin of the upland silt in the Fairbanks area, Alaska: Geol. Soc. America Bull., vol. 61, p. 1493.

———, 1951. An observation on wind-blown silt: Jour. Geology, vol. 59, pp. 399-401.

Smith, P. S., 1939. Areal geology of Alaska: U. S. Geol. Survey Prof. Paper 192.

Taber, Stephen, 1943. Perennially frozen ground in Alaska: its origin and history: Geol. Soc. America Bull., vol. 54, pp. 1433-1548.

Tuck, Ralph, 1938. The loess of the Matanuska Valley, Alaska: Jour. Geology, vol. 46, pp. 647-653.

———, 1940. Origin of the muck deposits at Fairbanks: Geol. Soc. America Bull., vol. 51, pp. 1295-1310.

UNIVERSITY OF SOUTH CAROLINA
COLUMBIA, SOUTH CAROLINA

[AMERICAN JOURNAL OF SCIENCE, VOL. 251, MAY 1953, PP. 337-361]

THE SYSTEM $MgO—Al_2O_3—H_2O$ AND INFLUENCE OF CARBONATE AND NITRATE IONS ON THE PHASE EQUILIBRIA

DELLA M. ROY, RUSTUM ROY AND E. F. OSBORN

ABSTRACT. Phase equilibria in the systems $MgO—Al_2O_3—H_2O$, $MgO—Al_2O_3—H_2O—CO_2$, and $MgO—Al_2O_3—H_2O—N_2O_5$ were investigated by means of hydrothermal and high temperature "dry" techniques. In the bounding binary system, $MgO—Al_2O_3$, it was found that solid solution of Al_2O_3 in $MgO \cdot Al_2O_3$ (spinel), which is extensive at solidus temperatures, decreases with decreasing temperature, and is very small below 800°C. In the system $MgO—H_2O$ the transition, brucite $\rightleftharpoons$ periclase + H_2O, takes place at 670°C at 20,000 psi., the transition temperature decreasing to 350°C under usual room atmospheric conditions. Compatibility relations were determined among the various phases in the system $MgO—Al_2O_3—H_2O$, and a lower stability temperature for spinel in the presence of excess H_2O was determined as 365°C. Below this temperature spinel is replaced by brucite + diaspore as stable phases.

The addition of CO_2 to the system $MgO—Al_2O_3—H_2O$ yielded the following CO_2-containing minerals: magnesite ($MgCO_3$), hydromagnesite ($3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O$) and hydrotalcite ($6MgO \cdot Al_2O_3 \cdot CO_2 \cdot 12H_2O$); and phase equilibria among these phases were determined. A nitrate analogue of hydrotalcite was also synthesized, and the relations between this compound and other phases in the system $MgO—Al_2O_3—H_2O—N_2O_5$ were studied.

INTRODUCTION

THE "mineralogical phase rule," first enunciated by V. M. Goldschmidt (1911), applies the principles of heterogeneous equilibrium to metamorphic mineral associations. This concept is derived from the assumption that there must be at least two degrees of freedom for a metamorphic mineral assemblage to exist over a sufficiently wide range of temperatures and pressures to occur in nature; and the maximum number of crystalline phases which can exist in equilibrium is therefore equal to the number of components, i.e., $P \leqslant C$. Extensive experimental study of high-temperature phase equilibria in "condensed" silicate systems has been carried out, which are especially applicable to problems in igneous petrology. The employment of techniques for the study of phase equilibria under high water pressures at moderately high temperatures supplements the data obtained using "dry" techniques, and

has extended the field of study to metamorphic mineral assemblages.

One of the most significant systems involved in an understanding of metamorphic petrology is the system $MgO—Al_2O_3—SiO_2—H_2O$, for a large number of metamorphic minerals appear as phases in this system. A complete investigation of the four-component system necessitates knowledge of the less complex bounding systems; and of the four bounding ternary systems, three have been previously described. The system $MgO—Al_2O_3—SiO_2$ was investigated by Rankin and Merwin (1916*a*) and later modified by Bowen and Greig (1924), Greig (1927), and recently by Foster (1950) and by Keith and Schairer (1952); the system $MgO—SiO_2—H_2O$ has been studied by Bowen and Tuttle (1949) and by Noll (1950); and the system $Al_2O_3—SiO_2—H_2O$ has been studied by several investigators, most recently by Roy and Osborn (1952*a*). The remaining ternary system to be studied is the system $MgO—Al_2O_3—H_2O$. Knowledge of this system in turn involves the bounding binary systems: $Al_2O_3—H_2O$, $MgO—H_2O$, and $MgO—Al_2O_3$.

The binary system $Al_2O_3—H_2O$ was described by Ervin and Osborn (1951), $MgO—H_2O$ by Bowen and Tuttle (1949) as part of their study of equilibria in the system $MgO—SiO_2—H_2O$, and $MgO—Al_2O_3$ by Rankin and Merwin (1916*b*). Results of the present investigation are not in disagreement with the relationships described by Ervin and Osborn for the system $Al_2O_3—H_2O$. Previous work in the system $MgO—Al_2O_3$ was largely concerned with liquidus and solidus relationships. We have extended the studies to lower temperatures. The transformation, brucite $\rightleftharpoons$ periclase + H_2O, as a function of pressure and temperature, was reinvestigated as part of the systematic study of the ternary system, with results different from those previously reported.

Complementary to the studies in the system $MgO—Al_2O_3—H_2O$, CO_2 and N_2O_5 were added as additional components. Several natural CO_2-bearing compounds are formed at lower temperatures as alteration products of spinel and brucite. Equilibria among these minerals was investigated. The nitrate ion was added, in analogy with CO_3^{-2}, because of the isomorphism of certain structures containing the carbonate and nitrate ions.

METHOD OF INVESTIGATION

Equipment used.—The hydrothermal equipment consisted of a series of furnaces designed to hold pressure vessels, either closed autoclaves or various types of bomb attached by means of pressure tubing to piston-type pumps which deliver the water pressure. A new pump (Roy and Osborn, 1952*b*) based on the compression of water in a stainless steel chamber by a commercial jack was most useful for attaining high pressures rapidly. Pressure vessels used included: (a) the autoclave designed by Morey and Ingerson (1937), (b) a modified smaller bomb of this type, (c) the apparatus designed by Tuttle (1948), and (d) long "test-tube" type bombs (Roy and Osborn, 1952*b*). Chromel wound furnaces were used, and temperature was controlled by Tagliabue "Celect-Ray," Leeds and Northrup, and Brown controllers. For temperatures above 2000°C an oxy-hydrogen torch was used; and temperatures up to 1850°C were attained with a 60Pt-40Rh "strip furnace." Globar furnaces, platinum-wound quenching furnaces, and a gas furnace were used for "dry" runs at lower temperatures. The X-ray diffraction equipment for examination of samples included the North American Phillips "Norelco" spectrometer, the GE-XRD-3 spectrometer, and powder cameras of radius 7.16 cm. Cu-Kα radiation was used. A differential thermal analysis apparatus was used for a few runs.

Method of investigation.—Starting materials included C. P. oxides, fired to high temperatures, finely powdered oxide mixtures, magnesia-alumina mixtures prepared by evaporating solutions of magnesium and aluminum nitrates and heating to about 500°C, and natural and synthetic samples of brucite, hydrotalcite, and spinel. Magnesia-alumina samples were pressed into triangular cones together with an organic binder, fused in the oxy-hydrogen torch, and quenched in water. They were examined, and then heat-treated at lower temperatures in the strip furnace, Pt quenching furnace, globar, or gas furnace, or in hydrothermal bombs. Hydrothermal samples were held in small platinum envelopes surrounded by more of the sample, as a buffer, in a larger envelope. One to four samples were rolled, and inserted in "test-tube" bombs, with a stainless steel rod on top to minimize convection currents. The samples were treated for periods varying from a few minutes to a few weeks,

then removed and examined under the petrographic microscope and by X-ray diffraction techniques.

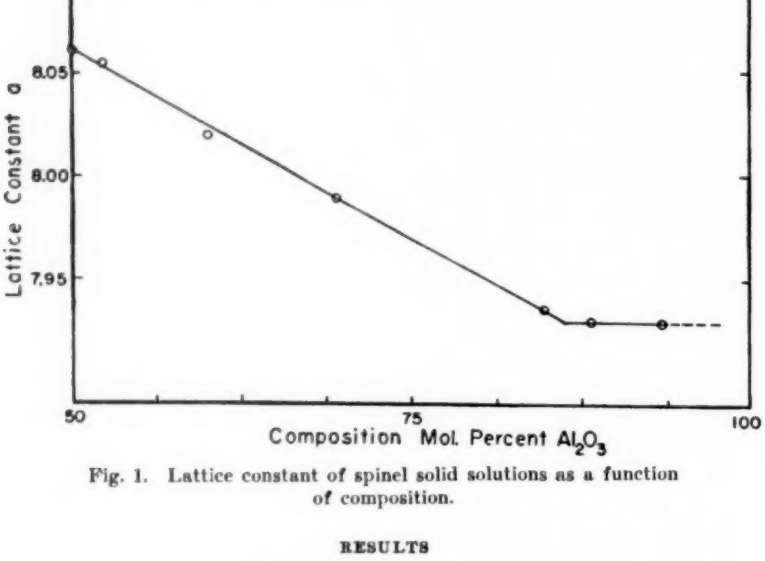


Fig. 1. Lattice constant of spinel solid solutions as a function of composition.

RESULTS

The System MgO—Al_2O_3

Spinel solid solutions.—Magnesia-alumina mixtures containing 50, 52, 60, 70, 85, 88, and 94 mol per cent Al_2O_3 were fused in the oxy-hydrogen torch, quenched, and examined under the petrographic microscope and by means of X-ray diffraction patterns. A homogeneous isotropic spinel solid solution was observed in compositions from 50 to 85 mol per cent Al_2O_3, whereas the 88 per cent mixture contained some corundum. The unit cell dimension, a, of the spinel solid solution is shown in figure 1 as a function of composition. The lattice dimension is seen to decrease from 8.06 for pure $MgO \cdot Al_2O_3$ to 7.935 for $15MgO : 85Al_2O_3$ and 7.93 for $12MgO : 88Al_2O_3$, beyond which there is no further change in the lattice dimension, and also corundum is present as a second phase. The point of maximum solid solution is taken as 86 mol per cent (approximately 94 wt. per cent) Al_2O_3, at the intersection of the two curves on the graph (figure 1). The maximum extent of solid solution agrees reasonably well with that deter-

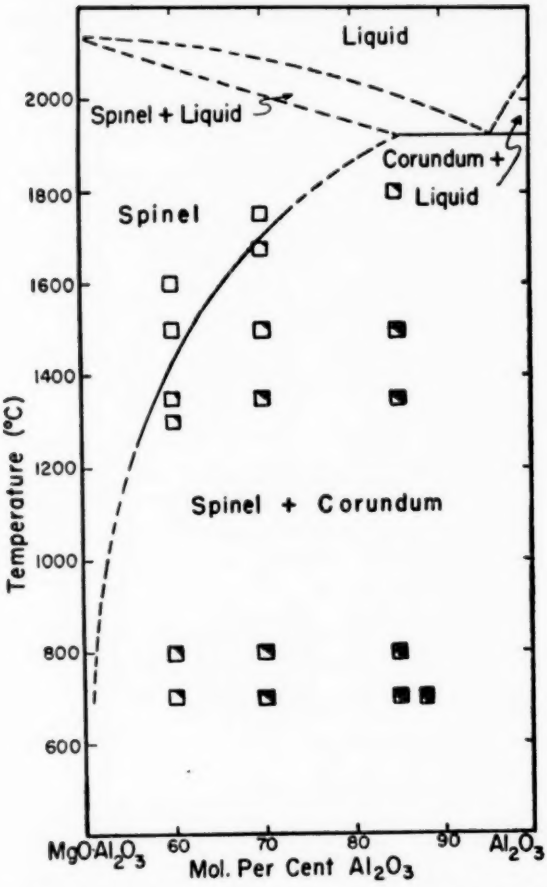


Fig. 2. Phase equilibrium diagram for the system $MgO \cdot Al_2O_3$—Al_2O_3. Squares represent runs, with darkened portion indicating per cent of corundum present.

mined by Clark (1934), 92.9 weight per cent. The lattice constant for pure spinel, a = 8.06 ± 0.005 agrees well with Clark's value (8.06), and the value for the maximum solid solution, a = 7.93 ± 0.005 corresponds to that of Clark, a = 7.93. These values and all others in this paper are in kX units.

Exsolution of solid solutions.—The solid solutions described above were heat-treated at lower temperatures, both "dry"

and hydrothermally. A summary of the data obtained for the system $MgO \cdot Al_2O_3$—Al_2O_3 is given in table 1, and the data are illustrated in the diagram of figure 2. The extent of solid solution is seen to decrease from 86 mol per cent Al_2O_3 at solidus temperatures to 60 mol per cent at 1450°C; and the amount of solid solution at 700° to 800°C is negligible. Exsolution of corundum from the high temperature spinel solid solutions was readily detectable under the microscope, and corundum as a second phase was detected in the X-ray diffraction patterns of exsolved samples. Percentages of spinel and alumina were estimated both optically, and by comparison of the X-ray diffraction patterns with patterns of standards made by grinding together spinel and corundum after each had been fired separately.

Three different factors indicated complete (or very nearly complete) exsolution at 700°C: (a) the d-spacings of the exsolved spinel returned to almost those of pure $MgO \cdot Al_2O_3$; (b) the comparison of relative intensities of the spinel and corundum in exsolved samples and in mechanical mixtures was close; and (c) the percentages of spinel and corundum estimated optically were those to be expected for complete exsolution.

TABLE 1

Data on Exsolution of Spinel Solid Solutions

High-Temperature Runs

Composition Mol Per cent Al_2O_3	Run No.	Temp. (°C)	Time (hrs)	Phases Present*
60	4332	1600	½	spinel ss
60	4579	1500	18	spinel ss
60	4504	1350	48	spinel (+v.l. cor)
60	4895	1300 ± 25	24	spinel (+v.l. cor)
70	4920	1750 ± 10	5 min.	spinel ss
70	4921	1675 ± 10	5 min.	spinel (+v.l. cor)
70	4580	1500 ± 10	18	spinel + 25% cor
70	4526	1350	48	spinel + 35% cor
85	4918	solidus		spinel ss
85	4919	1800 ± 10	5 min.	spinel + 35% cor
85	4581	1500 ± 10	18	spinel + 50% cor
85	4527	1350	48	spinel + 60% cor
88	4676	solidus		spinel + 15% cor

TABLE 1 (Cont.)

Hydrothermal Runs

Composition Mol Per cent Al_2O_3	Run No.	Temp. (°C)	Time (days)	Pressure (psi.)	Phases Present
60	4520	800 ± 15	12	10,000	spinel + 20% cor
60	4677	700	27	16,000	spinel + 20% cor
70	4518	800 ± 15	12	10,000	spinel + 30% cor
70	4678	700	27	16,000	spinel + 35% cor
85	4473	795 ± 10	3	10,000	spinel + cor
85	4679	700	27	16,000	cor + 40% spinel
88	4680	700	27	16,000	cor + 30% spinel

* Abbreviations: cor = corundum
v.l. = very little

Variation in lattice dimensions of $MgAl_2O_4$.—A variation in the lattice constant of $MgAl_2O_4$ prepared by different methods was observed. Spinel grown hydrothermally was found to have a slightly larger unit cell than that of fused $MgAl_2O_4$. The lattice dimensions of fused spinel, and of that sintered at 1400°C were approximately the same, a = 8.060, whereas those of spinel grown hydrothermally were different. The spinel grown hydrothermally from mechanically mixed oxides has the lattice dimension, a = 8.071 ± 0.005, and that grown hydrothermally from the nitrate decomposition product, a = 8.073 ± 0.005. A possible explanation of the difference between the dimensions of the spinel grown hydrothermally at lower temperatures and that formed either by fusion or sintering at high temperatures might be the presence of some water in the lattice of the sample grown hydrothermally. No significant weight loss was found, however, on firing the hydrothermal samples at 1400°C. Probably some rearrangement of magnesium and aluminum ions occurs between the higher and lower temperatures causing this slight change in the lattice dimensions.

The System MgO—H_2O

Preliminary runs.—The system MgO—H_2O involves the reaction, MgO (periclase) + $H_2O \rightleftharpoons Mg(OH)_2$ (brucite). The high reactivity of MgO with H_2O unless "dead burned" (heated to above about 1400°C) is well known; and under high

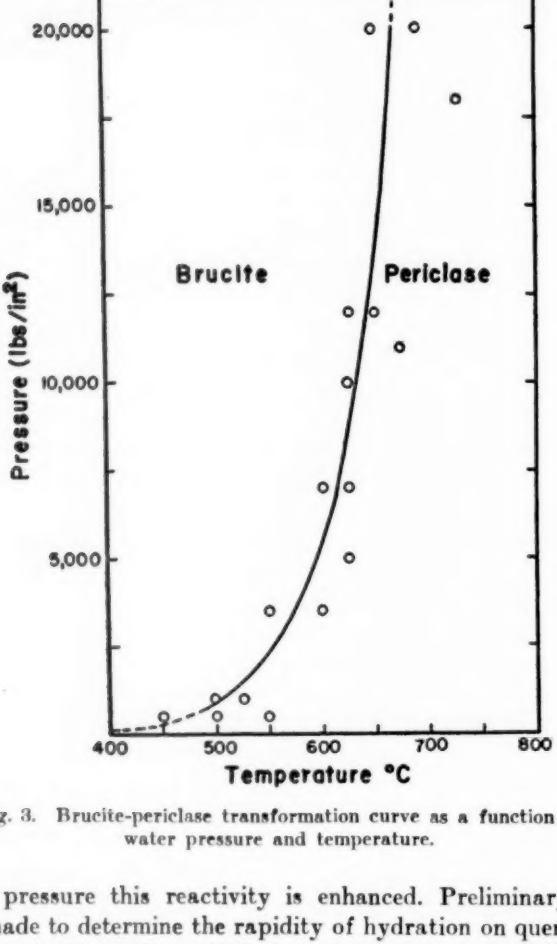


Fig. 3. Brucite-periclase transformation curve as a function of water pressure and temperature.

water pressure this reactivity is enhanced. Preliminary runs were made to determine the rapidity of hydration on quenching. Brucite, C. P. MgO, and MgO recrystallized at 1400°C were heated dry in the Tuttle apparatus for a minimum period of about 20 minutes required to bring the apparatus to a temperature of 830°C. A water pressure of 8,000 psi. was then applied and the samples immediately quenched in a stream of water, requiring only ½ minute. The brucite and C. P. MgO yielded mostly brucite with a small amount of periclase, whereas the recrystallized MgO (1400°C heat treatment) was about 30

per cent hydrated to brucite. Thus, C. P. periclase hydrated almost completely, and recrystallized periclase partly during the quenching, and periclase apparently does not form by the dehydration of brucite during quenching by this technique.

Results.—All runs were made in the Tuttle apparatus with the full water pressure applied throughout the run to eliminate the possibility of periclase formation on quenching or during original heating. Starting materials were recrystallized MgO (1400°C), natural brucite, and synthetic brucite. Runs were of several hours' duration, times found necessary to effect dehydration at the temperature and pressure of many of the runs. The data obtained from over 100 runs are summarized in table 2, and the equilibrium diagram is given in figure 3. Throughout a wide range of temperatures and pressures the products obtained from the three samples at a given temperature and pressure contained all brucite; whereas at the same pressure with a small increase in temperature, the products contained a considerable amount of periclase (table 2). If, under the conditions of the experiments, the quenched sample was all brucite, it was considered that brucite is the stable phase; if as much as 20 to 30 per cent of the sample was periclase, it was considered that periclase is the stable phase with the brucite present being formed by hydration at lower temperatures. The results using these criteria were reasonably consistent.

The transformation, brucite $\rightleftharpoons$ periclase + H_2O, was found to take place at 475°C at the lowest pressure studied, 500 psi., and 670°C at 20,000 psi. A differential thermal analysis run was made in air, heating natural brucite 10°C per minute. Beginning of dehydration occurred at 355°C, which agrees reasonably well with the value given by Huttig and Frankenstein (1929), 320-340°C, for dehydration in an atmosphere with pH_2O = 10 mm. The univariant curve of figure 3 may be reasonably extrapolated between 475°C and this lower temperature.

The System MgO—Al_2O_3—H_2O

Magnesia-alumina samples, using mixtures both of C. P. MgO and γAl_2O_3 and of the product formed by decomposing mixed nitrate solutions of magnesium and aluminum, were

TABLE 2

Summary of Equilibrium Data for the System $MgO—H_2O$

Starting Material	Serial No.	Temp. °C.	Press. psi.	Time (hrs.)	Phases* Present
Bru	4754	450 ± 3	500	10	Bru
Bru Syn ..	4755	450 ± 3	500	10	Bru
Per**	4756	450 ± 3	500	10	Bru
Bru	4728	500 ± 5	500	1	Bru + per
Bru Syn ..	4729	500 ± 5	500	1	Bru + per
Per	4730	500 ± 5	500	1	Bru + per
Bru	4787	501 ± 3	1,000	12	Bru
Bru Syn ..	4788	501 ± 3	1,000	12	Bru
Per	4789	501 ± 3	1,000	12	Bru
Bru	4751	525 ± 3	1,000	16	Bru + per
Bru Syn ..	4752	525 ± 3	1,000	16	Per + bru
Per	4753	525 ± 3	1,000	16	Per + bru
Bru	4757	550 ± 3	500	12	Bru + per
Per	4759	550 ± 3	500	12	Per + bru
Bru	4790	550 ± 3	3,500	5	Bru
Bru Syn ..	4791	550 ± 3	3,500	5	Bru
Per	4792	550 ± 3	3,500	5	Bru
Bru	4858	600 ± 5	3,500	24	Bru + per
Bru Syn ..	4859	600 ± 5	3,500	24	Per + bru
Per	4860	600 ± 5	3,500	24	Per + bru
Bru	4802	600 ± 5	7,000	12	Bru
Bru Syn ..	4803	600 ± 5	7,000	12	Bru
Per	4804	600 ± 5	7,000	12	Bru + v.l. per
Bru	4777	625 ± 3	5,000	3	Bru + per
Per	4779	625 ± 3	5,000	3	Per + v.l. bru
Bru	4799	622 ± 5	7,000	5	Bru + l. per
Per	4801	622 ± 5	7,000	5	Per + l. bru
Bru	4825	623 ± 3	10,000	12	Bru
Bru Syn ..	4824	623 ± 3	10,000	12	Bru
Bru	4853	623 ± 3	12,000	21	Bru
Bru Syn ..	4854	623 ± 3	12,000	21	Bru
Per	4855	623 ± 3	12,000	21	Bru + l. per
Bru	4845	647 ± 3	12,000	5	Per + bru
Bru Syn ..	4846	647 ± 3	12,000	5	Per + bru
Per	4847	647 ± 3	12,000	5	Per + bru
Bru	4913	650 ± 5	20,000	2½	Bru
Bru Syn ..	4914	650 ± 5	20,000	2½	Bru
Per	4915	650 ± 5	20,000	2½	Bru
Bru	4830	675 ± 3	11,000	6	Bru + per
Bru Syn ..	4821	675 ± 3	11,000	6	Per + bru
Per	4822	675 ± 3	11,000	6	Per + l. bru
Bru	4900	728 ± 5	18,000	16	Bru + per
Bru Syn ..	4901	728 ± 5	18,000	16	Bru + per
Per	4902	728 ± 5	18,000	16	Per + bru
Bru	4910	690 ± 10	20,000	7	Per + bru
Bru Syn ..	4911	690 ± 10	20,000	7	Per + l. bru
Per	4912	690 ± 10	20,000	7	Per + v.l. bru

* Abbreviations used: bru = brucite, syn = synthetic, per = periclase, v.l. = very little

** Periclase starting material in all cases was C. P. MgO, heated for ½ hr. at 1400°C.

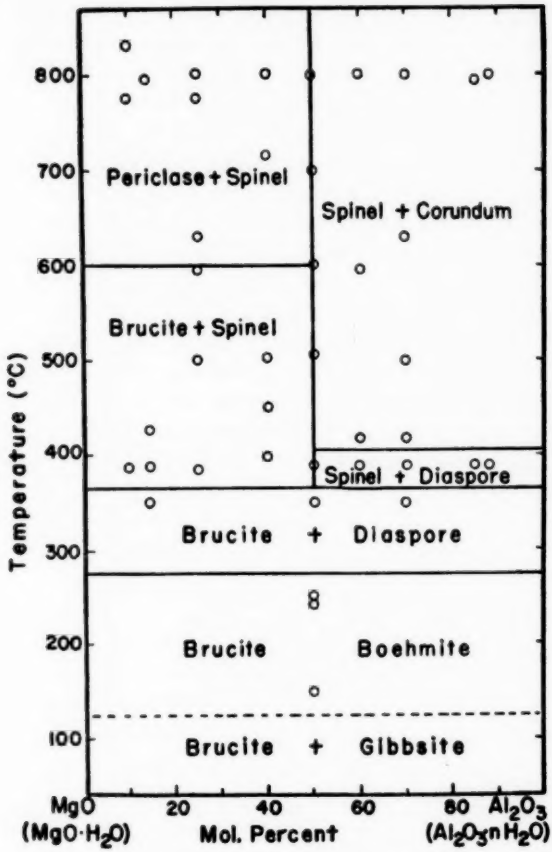


Fig. 4. Temperature-composition diagram for the system MgO—Al_2O_3—H_2O at 5,000 psi. water pressure. Circles represent composition and temperature of runs.

heated at temperatures ranging from 300° to 900°C with pressures varying from 5,000 to 20,000 psi. The equilibrium data obtained are summarized in table 3, and the phase equilibrium relations are presented diagramatically in figures 4 and 5. Figure 4 is a temperature-composition diagram for a constant water vapor pressure of 5,000 psi.; circles refer to runs listed in table 3. The pairs of crystalline phases coexisting with an aqueous phase as a function of temperature and composition are indicated. The phase equilibrium relations do not change

significantly with pressure except for the temperature of the separation of the regions of stability of periclase + spinel and brucite + spinel. The change in temperature of this boundary with pressure is given by the curve of figure 3.

Spinel and corundum coexist stably in the presence of water from the highest temperature studied, 800°C, down to 405 ± 5°C, where corundum is replaced by diaspore. The temperature for the transition, Al_2O_3 (corundum) + $H_2O \rightleftharpoons Al_2O_3 \cdot H_2O$ (diaspore) is apparently not affected by the presence of $MgO \cdot Al_2O_3$ as an additional phase, since this temperature agrees closely with that given by Ervin and Osborn (1951) for the diaspore-corundum transition in the system Al_2O_3—H_2O. As in the previous study (Ervin and Osborn, 1951) however, temperature of the diaspore-corundum transformation in the system MgO—Al_2O_3—H_2O is based only on the conversion of diaspore to corundum. The reverse reaction was not achieved.

TABLE 3

Data for the System MgO—Al_2O_3—H_2O

Summary of Equilibrium Hydrothermal Data

Composition Mol Per cent Al_2O_3	Run No.	Temp. °C.	Press. (psi.)	Time (days)	Phases Present*
10	4601	830	10,000	2¼	per + bru + spinel
10	4330	775	10,000	1	per + spinel + bru
10	4378	385	8,000	1	bru + spinel
14.3	4478	795	10,000	3	per + spinel
14.3	4388	428	6,000	8	bru + spinel
14.3	4462	388	20,000	8	bru + spinel
14.3	4514	350	20,000	7	bru + bo
25	4182	800	5,000	1	per + spinel
25	4331	775	10,000	1	per + spinel
25	4169	630	5,000	6	per + spinel + ?
25	4292	595	5,000	6	spinel + bru + per
25	4296	500	5,000	5	bru + spinel
25	4379	385	8,000	1	bru + spinel
40	4289	800	5,000	4	spinel + per
40	4135	716	5,000	1	spinel + per
40	4297	500	5,000	5	spinel + bru
40	4352	450	8,000	7	spinel + bru
40	4312	398	9,000	4	spinel + bru

TABLE 3 (cont.)

Composition Mol Per cent Al_2O_3	Run No.	Temp. °C.	Press. (psi.)	Time (days)	Phases Present*
50	4007	800	10,000	2	spinel
50	4011	700	10,000	5	spinel
50	4155	600	5,000	12	spinel
50	4244	505	8,000	13	spinel
50	4467	388	20,000	8	spinel
50	4512	350	20,000	7	bru + bo
50[2]**	5050	250	7,500	7	bru + bo
50[1]**	4995	245	5,000	10	bru + bo
50[2]	5065	150	2,000	4	bru + bo
50[1]	5066	150	2,000	4	bru + bo
60	4619	800	8,000	4	spinel + cor
60	4295	595	5,000	6	spinel + cor
60	4344	418	15,000	6	spinel + cor
60**	4721	390	5,000	8½	spinel + bo
70	4183	800	5,000	1	spinel + cor
70	4170	630	5,000	6	spinel + cor
70	4298	500	5,000	5	spinel + cor
70	4343	418	15,000	6	spinel + cor
70**	4722	390	5,000	8½	spinel + bo + di
70**	4540	350	10,000	14	bo + bru + di
85	4476	795	10,000	3	cor + spinel
85**	4723	390	5,000	8½	bo + spinel + di
88	4719	800	5,000	1	cor + spinel
88**	4724	390	5,000	8½	bo + di + spinel
		Data on Spinel Decomposition			
Natural	4264	450	7,500	11	spinel
Natural	4509	350	20,000	7	spinel
Natural	4630	300	15,000	25	spinel
Synthetic	5025	315	15,000	10	spinel
Synthetic[3]	4993	300	3,000	19	spinel + cor (+ bru?)
Synthetic[3]	4972	300	5,000	8	spinel + cor

* Abbreviations used: per = periclase, bru = brucite, bo = boehmite, cor = corundum, di = diaspore

** Diaspore seeds added

[1] $MgO + \gamma - Al_2O_3$ mixture

[2] MgO + gibbsite mixture

[3] Grinding runs

Spinel and diaspore coexist only over a narrow temperature range, between 405° ± 15°C and 365° ± 15°C, below which spinel has not been formed in the presence of water. Spinel,

made by sintering oxides at 1400°C, was partly decomposed when ground under pressure (Roy and Osborn, 1952*b*) at 300°C, yielding some corundum with perhaps a little brucite. The fact that corundum, not boehmite or diaspore, was one of the decomposition products is difficult for us to explain. The formation of stable phases would be expected on a complete breakdown of the spinel lattice. But there may be a strong tendency for Al to keep its surroundings of six oxygen ions which existed in the spinel lattice; and once the even small units of corundum were formed, it would be extremely difficult to break these units down.

Brucite and diaspore coexist below 365°C, and presumably down to the temperature below which boehmite is stable—about 275°C. In all cases the growth of diaspore was dependent on the use of "seed" crystals in the sample. Considerable diaspore growth took place on the seeds, indicated by original "skeleton" crystals surrounded by overgrowths, as well as much independent growth of lathlike diaspore crystals. Runs not seeded yielded boehmite as the second phase.[1] Periclase and spinel coexist from the highest temperatures down to the temperature where brucite becomes stable, about 600°C at 5,000 psi. and varying with pressure, as seen in figure 3.

The phase equilibria for a constant pressure of 5,000 psi. are illustrated by a series of composition triangles in figure 5. The advantage of this diagram over figure 4 is the depiction of "water-deficiency" triangles. Thus it is seen that spinel can coexist with the water phase down to a temperature of 365°C. It can exist stably below this temperature only where there is insufficient water to convert the assemblage completely to hydrates. Similar minimum temperatures for corundum and periclase are 405°C and 600°C at 5,000 psi. water pressure, but these crystals are stable at lower temperatures in the absence of an aqueous phase.

The System MgO—Al_2O_3—H_2O—CO_2

Mechanical mixtures of MgO and γAl_2O_3 and mixtures formed by decomposing magnesium and aluminum nitrate mixtures

[1] Diaspore was formed from an Al_2O_3 gel at 395°C and 32,000 psi. (heated for 7 days) without the use of seeds; however, no MgO was present, and this result applies therefore to the system Al_2O_3—H_2O confirming the results of Ervin and Osborn (1951). Comparably high pressures were not used with MgO—Al_2O_3 mixtures.

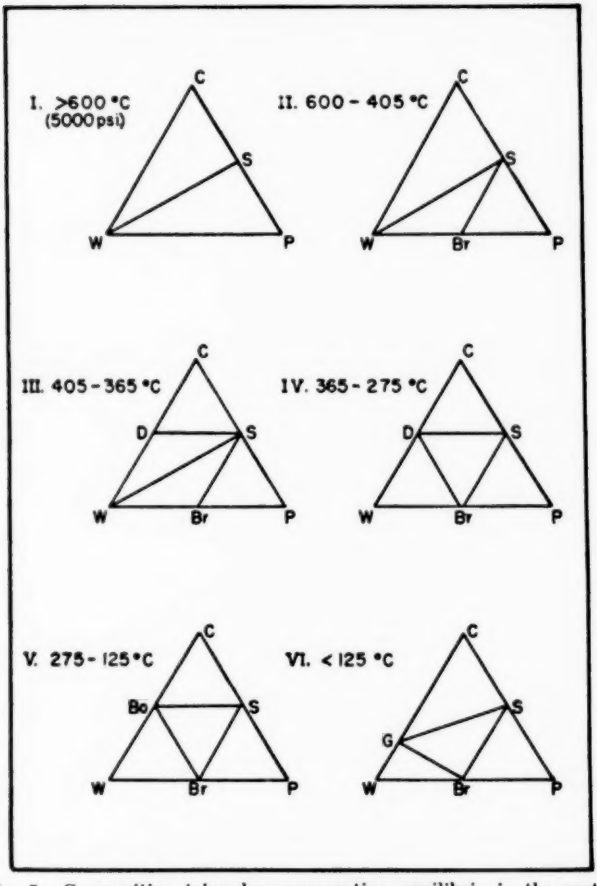


Fig. 5. Composition triangles representing equilibria in the system MgO—Al_2O_3—H_2O. Abbreviations used:
C = corundum, S = spinel, P = periclase,
W = water, Br = brucite, D = diaspore,
Bo = boehmite, G = gibbsite.

were used as the starting material, and CO_2 was added either as dry ice or $(NH_4)_2CO_3$. When dry ice was used, mixtures were run in closed Morey bombs; otherwise test-tube bombs could be used. Natural hydrotalcite from Snarum, Norway, and synthetic hydrotalcite prepared in this study, were also used as starting materials. Hydromagnesite from Crestmore, California, obtained through the courtesy of Professor J. Murdock,

was used for a comparison standard. Partial pressures of CO_2 were in most cases not calculated, although total pressure (H_2O and CO_2) was read on the gauges. Generally, therefore, conditions were not proper for producing the pure stoichiometric compounds, or for obtaining equilibrium data as a function of independent H_2O and CO_2 pressures.

Hydrotalcite was synthesized readily in all runs below 325°C, at total pressures of 2,000 to 20,000 psi.; and both natural and synthetic hydrotalcite decomposed above this temperature at pressures in the same range. The partial CO_2 pressure roughly estimated from gas laws on the basis of the total CO_2 introduced into the closed bomb, was varied from about 100 to 2,000 psi., with water pressure ranging from 1,000 to 20,000 psi. Within these ranges of estimated CO_2 and H_2O pressure, the maximum temperature of stability of hydrotalcite remained constant at 325° ± 10°C. Even a very low CO_2 partial pressure has little effect on this decomposition temperature as shown by the fact that natural hydrotalcite introduced into a bomb containing only pure water decomposed at this same temperature, at water pressures of 2,000 to 10,000 psi. The synthetic mineral

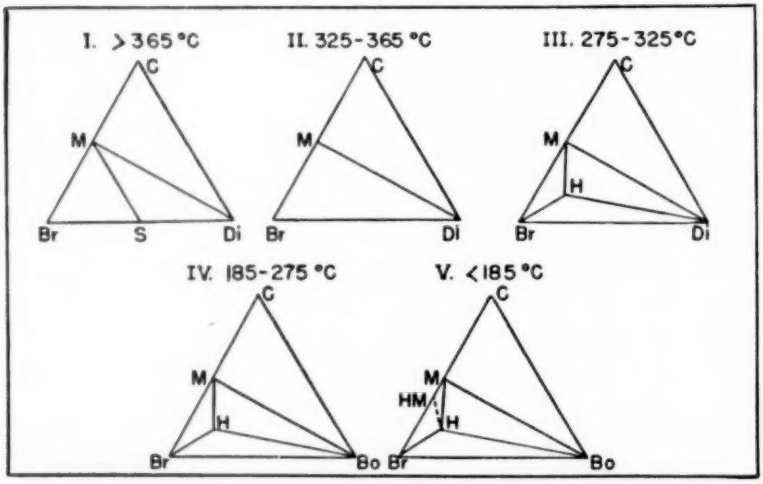


Fig. 6. The system $MgO—Al_2O_3—H_2O—CO_2$. Composition triangles are projections on the base of tetrahedra with H_2O at the top apex. Abbreviations used:

C = CO_2, Di = diaspore, S = spinel, Br = brucite
M = magnesite, H = hydrotalcite, HM = hydromagnesite
Bo = boehmite.

was essentially identical to the natural mineral from Snarum, Norway, having a similar X-ray diffraction pattern, and approximately the same index of refraction. X-ray data for this compound, compared with those of the natural mineral and the synthetic nitrate-analogue, are given in table 4. The average index of refraction was 1.500 ± 0.010 (compared with those of the natural mineral, $\omega = 1.511$ and $\epsilon = 1.495$). Crystals of synthetic hydrotalcite were never grown large enough to determine accurately the index of refraction or other optical data.

Hydromagnesite was synthesized at temperatures between 185°C and 110°C at water pressures in the range used (2,000 to 15,000 psi.), from mixtures made by adding $(NH_4)_2CO_3$ to either C. P. MgO or recrystallized MgO. The material was fine grained, but the index of refraction was about the same as that of the natural mineral hydromagnesite, 1.540. X-ray data for the natural and synthetic mineral are given in table 5.

TABLE 4

X-ray Spacings for Hydrotalcite Minerals

Synthetic Hydrotalcite # 4594		Natural Hydrotalcite # 266.1		Synthetic N-Hydrotalcite # 4463	
d	I/I°	d	I/I°	d	I/I°
7.69	1.0	7.63	1.0	7.97	1.0
3.85	.4	3.82	.5	3.99	.6
2.58	.25	2.56	.1	2.65	.1
2.295	.2	2.283	.05	2.423	.05
1.941	.2	1.941	.1	2.082	.2
1.526	.1	1.524	.05	1.630	.02
1.495	.1	1.495	.05	1.594	.05

Phase equilibrium data are summarized in table 6, and the relations are expressed by compatibility triangles in figure 6. These represent tetrahedra in the quaternary system MgO—Al_2O_3—H_2O—CO_2, with H_2O at the apex of the large tetrahedron, and the relations projected on the base. The triangles represent combinations of three phases in equilibrium with an aqueous phase.

The System MgO—Al_2O_3—H_2O—N_2O_5

The addition of a small amount of the nitrate ion to mixtures in the system MgO—Al_2O_3—H_2O was found to produce effects

TABLE 5

X-ray Data on Hydromagnesite

Hydromagnesite* (synthetic)		Hydromagnesite** (natural)	
d	I/I°	d	I/I°
9.31	.4	9.19	.5
6.46	.5	6.40	.6
5.87	1.0	5.80	1.0
4.55	.15	4.46	.2
4.17	.3	4.17	.2
4.08	.05	4.06	.1
3.80	.05	3.82	.1
3.51	.1	3.50	.1
3.33	.2	3.32	.3
3.17	.15	3.20	.05
		3.15	.05
		3.10	.05
2.91	1.0	2.90	1.0
		2.83	.05
		2.77	.05
2.70	.2	2.69	.4
2.52	.15	2.50	.3
		2.41	.05
		2.35	.1
2.30	.15	2.30	.4
2.21	.2	2.20	.05
2.16	.3	2.18	.05
2.11	.05	2.09	.05
		2.036	.05
1.99	.2	1.99	.1
		1.97	.05
1.93	.05	1.93	.1
		1.906	.05
1.86	.05	1.864	.05

* Synthetic hydromagnesite prepared at 150°C and 10,000 psi.; X-ray data measured on the North American Phillips "Norelco" spectrometer, Cu-Kα radiation. Values in kX units.

** Natural hydromagnesite from Crestmore, California. The d-spacings are those measured by Professor J. Murdock, Department of Geology, U.C.L.A.

similar to those produced by the addition of the carbonate ion. Magnesia-alumina mixtures were made by the methods described previously, and the nitrate ion was added in the form of small quantities of magnesium and aluminum nitrates. A nitrate analogue of hydrotalcite was formed and had a stable

existence below 423° ± 5°C, in the range of total pressure "N_2O_5" and H_2O from 2,000 to 20,000 psi., i.e., about 100°C higher than that of the carbonate structure. The properties were found to be similar, the nitrate compound having an average index of refraction 1.510 ± 0.010, compared with 1.500 ± 0.010 for the synthetic carbonate-hydrotalcite. A close comparison is also seen between the X-ray pattern for this compound, given in table 4, and that for the natural and synthetic CO_2-containing minerals.

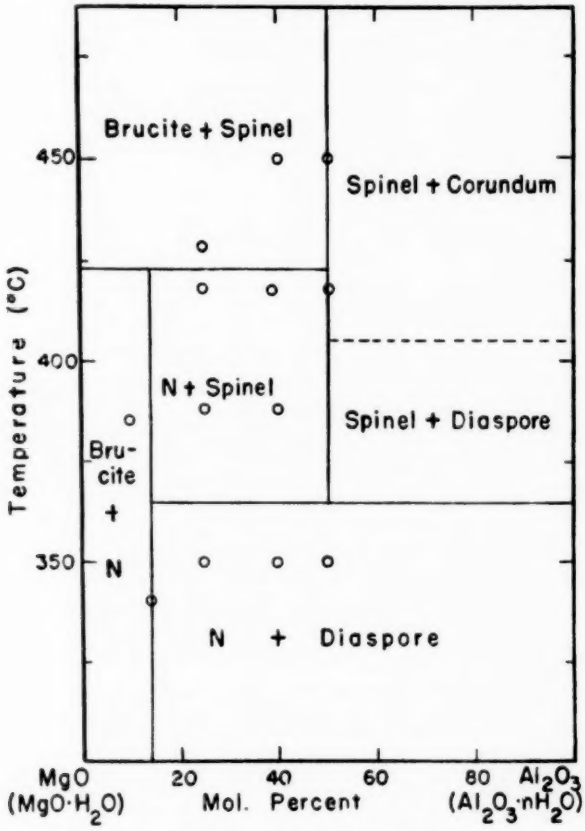


Fig. 7. Equilibria in the system MgO—Al_2O_3—H_2O—N_2O_5. The equilibria are shown for a water pressure of 10,000 psi., with the aqueous phase containing a small amount of nitrate ion. Circles represent composition and temperature of runs. N = nitrate-hydrotalcite phase.

A summary of the phase equilibrium data for this system is given in table 7, and the equilibria are represented in the diagram of figure 7. The equilibria are represented as crystalline phases in equilibrium with an aqueous phase containing a small amount of the nitrate ion, at a pressure of 10,000 psi. The phases compatible at higher temperatures are the same as in the system $MgO—Al_2O_3—H_2O$; but below 423°C the nitrate-hydrotalcite is stable, existing in equilibrium with either brucite or spinel.

TABLE 6

Equilibrium Data for the System $MgO—Al_2O_3—H_2O—CO_2$

Composition Mol Per cent Al_2O_3	Run No.	Temp. (°C)	Press. (psi.)	Time (hrs)	Phases Present*
0	5082	190	4,000	72	bru + $MgCO_3$
0	5084	165	2,000	10	bru + hydromag
0	5026	110	10,000	4	bru + hydromag
10	4627	248	16,000	12	$MgCO_3$ + hyd
10	4632	175	16,000	24	$MgCO_3$ + hyd + bo
10	5083	190	4,000	72	$MgCO_3$ + boehm + v.l. hyd
10	5085	165	2,000	10	hyd + bru
14.5	4684	375	16,000	120	bru + $MgCO_3$ + spinel
14.5	4644	370	16,000	24	$MgCO_3$ + bru + bo
14.5**	4780	350	5,000	96	$MgCO_3$ + bru + bo + di
14.5	4648	330	16,000	48	bru + $MgCO_3$ + bo
14.5	4662	320	16,000	72	hyd + $MgCO_3$ + bru
14.5	4626	248	16,000	12	$MgCO_3$ + hyd
14.5	4631	175	16,000	24	hyd + $MgCO_3$ + bo
25	4649	330	16,000	48	bru + $MgCO_3$ + bo
25	4663	320	16,000	72	bo + $MgCO_3$ + hyd (+ bru)
25	4655	310	16,000	24	hyd + $MgCO_3$ + bo
25	4750	250	6,000	48	hyd + bo + bru
25	4595	195	10,000	96	hyd + $MgCO_3$ + bo
40**	4513	350	20,000	168	bru + hyd + di
50**	4781	350	5,000	96	$MgCO_3$ + bo + di

* Abbreviations used:
bru = brucite,
bo = boehmite
di = diaspore
hydromag = hydromagnesite $\{3MgCO_3 \cdot Mg(OH)_2 \cdot 3H_2O\}$
hyd = hydrotalcite $\{6MgO \cdot Al_2O_3 \cdot CO_2 \cdot 12H_2O\}$

** Diaspore seeds added

TABLE 7

Equilibrium Data for the System $MgO—Al_2O_3—H_2O—N_2O_5$

Composition Mol Per cent Al_2O_3	Run No.	Temp. (°C)	Press. (psi.)	Time (hrs)	Phases Present*
10	4393	385	7,500	168	bru + N
15	4553	340	10,000	168	N + v.l. bo + bru
25	4390	428	7,000	192	bru + spinel
25	4341	418	15,000	144	N + l. spinel
25	4463	388	20,000	108	N + v.l. spinel
25	4432	350	8,000	144	N + bo
40	4352	450	8,000	168	spinel + bru
40	4340	418	15,000	144	spinel + N
40	4312	398	9,000	108	N + spinel
40	4283	350	9,000	120	bo + N
50	4266	450	7,500	264	spinel
50	4342	418	15,000	144	spinel
50	4284	350	9,000	120	bo + N

* Abbreviations used: N = NO_3-hydrotalcite
bru = brucite
bo = boehmite

DISCUSSION AND CONCLUSIONS

Spinel having a composition close to $MgAl_2O_4$ has a widespread occurrence in metamorphic rocks. No considerable excess of Al_2O_3 over that required by the formula has been reported in natural spinels, except for crystals containing appreciable quantities of cations other than Mg^{2+} and Al^{3+} (Bobkov and Kazitsyn, 1951). In view of the equilibrium relations (fig. 2), "excess" Al^{3+} in magnesium aluminate should occur only if temperatures during formation were exceedingly high. A lower stability temperature for spinel in the presence of relatively high water pressures has been determined as 365°C. Most natural occurrences of spinel suggest a moderately high temperature of formation, but a few occurrences are in ore veins. Spinel may be a useful temperature indicator in these deposits, suggesting a minimum temperature for the formation of hydrothermal spinel of about 365°C.

Spinel is commonly associated with corundum rather than one of the alumina hydrates, and this is again to be expected from the large compatibility field of the two minerals. One

occurrence of spinel with diaspore was reported by Tilley (1935), but the diaspore was closely associated with clinochlore, and Tilley believed that both the diaspore and clinochlore were not in equilibrium with the other minerals of the assemblage. Inasmuch as the equilibrium relations determined in the present study place a narrow temperature range of about 365-405°C for the stable coexistence of spinel and diaspore, few natural associations of these two minerals would be expected.

Periclase is not a common mineral in nature, and in its known occurrences periclase is largely the result of dissociation of dolomite. Wherever periclase has been exposed to the action of H_2O, it is either partly or completely converted to brucite; or if CO_2 was present, to hydromagnesite. Brucite is much more common than periclase, occurring as a low-temperature hydrothermal vein mineral in many serpentine rocks, and also occurring in limestones and marbles. The predominance of brucite over periclase in reported occurrences is to be expected from the rapidity with which periclase hydrates to brucite, and also from the fact that brucite is stable to moderately high temperatures when the water pressure is sufficiently high (fig. 3).

The known occurrences of hydrotalcite are few, although this may be partly due to its close physical resemblance to talc, making difficult its identification in the field. Typical occurrences are in serpentines, in talc schists, and as an alteration product of spinel where, in some cases, hydrotalcite has formed as pseudomorphs after spinel. Inasmuch as the upper stability temperature of hydrotalcite is lower than the lower limit for spinel, it would appear that spinel and hydrotalcite can never exist stably together, and that if equilibrium has been established, the spinel must be completely changed to hydrotalcite.

Hydromagnesite is a typical low-temperature mineral, occurring in hydrothermal veinlets and crusts in serpentine, and in altered magnesium-rich igneous rocks. It occurs as an alteration product of brucite and dolomite; and other associated minerals include calcite, aragonite, magnesite, artinite, pyroaurite (isomorphous with hydrotalcite), and deweylite. The upper stability temperature for the formation of hydromagnesite determined in the present study (about 185°C) may be applied to such occurrences within certain limitations as mentioned below.

In conclusion, it should be stated that the phase equilibrium relations determined in the present study are applicable to conditions in nature only with certain limitations. First, they are equilibrium relations, and in many cases natural mineral associations give evidence of lack of equilibrium. The equilibria determined here cannot in such cases predict the mineral associations or temperature of formation. Second, the equilibria apply to relatively pure crystalline phases, and extensive solid solution of another component in a crystalline phase will change the temperatures for a given reaction or may even change the nature of the reaction. Third, the relations have been determined in the presence of excess H_2O. In the low-temperature region where hydrates are the stable phases in the presence of excess H_2O, anhydrous compounds will be stable if there is insufficient water to convert the oxides completely to hydrates. Finally, where phases containing nitrate or carbonate ions are involved, very high or extremely low nitrate or carbonate ion concentrations may significantly affect temperatures of stability of these phases.

SUMMARY

Phase equilibria in the ternary system MgO—Al_2O_3—H_2O were determined, and new data for the systems MgO—Al_2O_3 and MgO—H_2O are presented. In the system MgO—Al_2O_3, solid solution of Al_2O_3 in $MgO \cdot Al_2O_3$ (spinel) was found to decrease with decreasing temperature, and is very small in extent below 800°C. A new pressure-temperature curve is given for the reaction, periclase + $H_2O \rightleftharpoons$ brucite, in the system MgO—H_2O, the reaction taking place at lower temperatures than those previously reported, about 600°C at 5,000 psi. The relations determined in the two binary systems hold true for the ternary system, periclase existing in equilibrium with $MgO \cdot Al_2O_3$ above 600°C (at 5,000 psi.), and with brucite below 600°C. Equilibria in the system Al_2O_3—H_2O (Ervin and Osborn, 1951) apparently are not changed by the addition of the component MgO, and corundum exists in equilibrium with spinel above 405°C (at 5,000 psi.), and diaspore with spinel below 405°C. Spinel is no longer stable in the presence of excess H_2O below 365°C, and is replaced by the hydrates, brucite and diaspore. Boehmite is the phase in equilibrium with brucite below 275°C,

although it ordinarily appears also in the diaspore stability field if the samples are not seeded with diaspore crystals.

Equilibria in the portion of the system $MgO—Al_2O_3—H_2O—CO_2$ studied involve three additional minerals: magnesite, hydromagnesite, and hydrotalcite, which are respectively, binary, ternary, and quaternary phases. In the presence of excess H_2O, and moderate CO_2 pressures magnesite is stable at high temperatures, hydrotalcite is stable below 325°C, and hydromagnesite below 185°C. The nitrate ion was added to the system $MgO—Al_2O_3—H_2O$, in analogy with the carbonate ion, and a nitrate analogue of hydrotalcite was found to form stably up to 425°C.

The phase equilibria and stability relations among minerals in the systems $MgO—Al_2O_3—H_2O$ and $MgO—Al_2O_3—H_2O—CO_2$ are discussed in terms of natural mineral associations, and it is suggested that points such as the lower stability temperature of spinel in the presence of excess H_2O may be used as fixed points on a geologic thermometry scale.

ACKNOWLEDGMENT

This investigation is part of a research program on the stability relations of minerals at high pressure and temperature sponsored by the Geophysics Branch of the Office of Naval Research.

REFERENCES

Bobkov, N. A., and Kazitsyn, Iu. V., 1951. The new mineral magnalumoxide: Vesceiuzn. Mineralog. Obsch. Zapiski, 2nd ser., vol. 80, (2), pp. 108-121.

Bowen, N. L., and Greig, J. W., 1924. The system alumina—silica: Am. Ceramic Soc. Jour., vol. 7, pp. 238-54; and ibid., p. 410.

———, and Tuttle, O. F., 1949. The system $MgO—SiO_2—H_2O$: Geol. Soc. America Bull., vol. 60, pp. 439-60.

Clark, G. L., Howe, E. E., and Badger, A. E., 1934. Lattice dimensions of some solid solutions in the system $MgO—Al_2O_3$: Am. Ceramic Soc. Jour., vol. 17, pp. 7-8.

Ervin, G., and Osborn, E. F., 1951. The system $Al_2O_3—H_2O$: Jour. Geology, vol. 59, pp. 381-394.

Foster, W. R., 1950. Synthetic sapphirine and its stability relations in the system $MgO—Al_2O_3—SiO_2$: Am. Ceramic Soc. Jour., vol. 33, pp. 73-84.

Goldschmidt, V. M., 1911. Die Kontaktmetamorphose im Kristianiagebiet: Kristiania Vidensk. Skr., I. Math.-naturv. Kl., 11, p. 123.

Greig, J. W., 1927. Immiscibility in silicate melts, I-II: Am. Jour. Sci., 5th ser., vol. 13, pp. 1-44; 133-154.

Huttig, G. F., and Frankenstein, W. Z., 1929. Zur Kenntnis des Systems MgO/H_2O: Zeitschr. anorg. allg. Chemie, vol. 185, p. 403.

Keith, M. L., and Schairer, J. F., 1952. The stability field of sapphirine in the system $MgO—Al_2O_3—SiO_2$: Jour. Geology, vol. 60, pp. 181-186.

Morey, G. W., and Ingerson, E., 1937. A bomb for use in hydrothermal experimentation: Am. Mineralogist, vol. 22, pp. 1121-1122.

Noll, W., 1950. Syntheses in the system MgO—SiO_2—H_2O: Zeitschr. anorg Chemie, vol. 261, pp. 1-25.

Rankin, G. A., and Merwin, H. E., 1916*a*. The ternary system MgO—Al_2O_3—SiO_2: Am. Jour. Sci., 4th ser., vol. 45, pp. 301-325.

———, ———, 1916*b*. The ternary system CaO—MgO—Al_2O_3: Am. Chemical Soc. Jour., vol. 38, p. 571.

Roy, R., and Osborn, E. F., 1952*a*. Studies in the system alumina—silica—water. Problems of Clay and Laterite Genesis Symposium, Am. Inst. Min. Met. Eng., pp. 76-80.

———, ———, 1952*b*. Some simple aids in the investigation of hydrothermal mineral systems: Econ. Geology, vol. 47, pp. 717-721.

Tilley, C. E., 1935. Metasomatism associated with the greenstone hornfelses of Kenidjack and Bottalack, Cornwall: Mineralog. Mag., vol. 24, pp. 181-202.

Tuttle, O. F., 1948. A new hydrothermal quenching apparatus: Am. Jour. Sci., vol. 246, pp. 628-635.

School of Mineral Industries
The Pennsylvania State College
State College, Pennsylvania

[American Journal of Science, Vol. 251, May 1953, Pp. 362-368]

SANGAMON SOIL AND EARLY WISCONSIN LOESSES AT CLEVELAND, OHIO

GEORGE W. WHITE

ABSTRACT. In a large gravel pit in the Mill Creek Valley one mile southeast of Garfield Park, Cleveland, Ohio, as much as 5 feet of Sangamon soil ("gumbosand") rests upon leached Illinoian gravel and in turn is overlain by a Wisconsin sequence of two fossiliferous loesses, lacustrine clay and silt, and till. The lower loess is about 3½ feet thick and includes an upper one-foot layer weathered to an incipient soil. The upper loess is 1½ feet thick and calcareous throughout. These fossiliferous loesses are interpreted as early Wisconsin, probably pre-Tazewell (Farmdale?) and Tazewell (pro-Tazewell?). The lacustrine material overlying the loess is assigned to an early Tazewell (pro-Tazewell?) age. The till at the top of the section is late Cary; Tazewell till and early Cary till—elsewhere present in northeastern Ohio—are absent from this section.

SEVERAL localities have been discovered in Columbiana, Portage, Cuyahoga and Mahoning counties, Ohio, where weathered Illinoian drift underlies fresh Wisconsin drift (White, 1951*b*). At one locality in the margin of Cleveland, Cuyahoga County, not only is a complete Sangamon soil profile preserved but, in addition, the profile is overlain by two layers of fossiliferous loess and by lacustrine deposits, as well as by Wisconsin till. These drift sections have been found in the Allegheny plateau in northeastern Ohio in the course of cooperative ground-water investigation by the U. S. Geological Survey and the Ohio Division of Water.

One of the most important localities in the Cleveland area for commercial gravel is the Mill Creek Valley in Garfield and Maple Heights, just southeast of Garfield Park in the southeast margin of Cleveland (Smith, 1949, p. 13). Several large gravel pits have been opened on either side of Broadway along a 1½ mile stretch of the valley from Henry southeast to the corner of McCracken Road and Broadway (Cleveland quadrangle). Immediately west of the Pennsylvania Railroad crossing at McCracken Road, 200 feet south of the common corner of Warrensville, Bedford, and Newburg townships, is the conspicuous but now abandoned dredge pit of the Schmidt Brothers Sand and Gravel Company. Immediately adjacent on the west is the large shovel pit of the Cleveland Sand and Gravel Com-

pany, about 400 yards from the railroad crossing. The section exposed in the active pit is shown in figure 1 and a description of a section in the central part of the pit is as follows:

Wisconsin	Thickness		To base	
Late Cary	Ft.	In.	Ft.	In.
Clay loam, silty, dark gray	0	6	0	6
Clay loam, silty, yellow and gray mottled	1	4	1	10
Till, brown, weathered	1	2	3	0
Till, brown, silty, clayey, moderately pebbly, many shale fragments, calcareous	3	6	6	6
Sand, brown, dirty, with pebbles and shale fragments, very calcareous	0	8	7	2
pre-Late Cary (pro-Tazewell?)				
Varved silt, brownish yellow, with some fine sand layers, calcareous	2	6	9	8
Varved silt and clay, blue-gray, varves 1/64-½", coarsest toward top, calcareous, wood fragments in basal 1 foot	16	6	26	2
pro-Tazewell (?)				
Loess, light yellow, some darker yellow-brown bands, fossiliferous, very calcareous	1	6	27	8
Farmdale (?)				
Loess, dark brown, clayey, weathered, old soil, noncalcareous	1	1	28	9
Loess, yellow-brown to gray-brown, varies from noncalcareous to weakly calcareous, fossiliferous, more so in lower part	2	6	31	3
Sangamon				
Silt, very clayey, reddish brown, noncalcareous	0	4	31	7
Silt, very clayey, brown to dark brown, noncalcareous, old soil horizon, odor of decayed vegetation at places, near top some charcoal fragments, and a few snails (adventitious?)	1	8	33	3
Sandy silt, clayey, greenish gray, noncalcareous, a few sandstone pebbles; old soil derived from gravel ("gumbosand")	3	6	36	9
Limonite, silty, red-brown, hard, botryoidal, concretionary, varies from ½ to 1½"	0	1	36	10
Illinoian				
Sand, silty, yellow-brown, a few pebbles, noncalcareous, bedding obliterated; old weathered gravel	3	0	39	10
Gravel, fine-grained, and sand, brown, leached, somewhat indurated, in horizontal layers	3	0	42	10
Gravel and sand, brown, calcareous	6	0	48	10
Gravel and sand, gray, calcareous; 40′ exposed, 30′ reported below floor level	70	0	119	

Samples of the two loesses were collected by A. B. Leonard in company with the writer for the recovery and study of the

gastropod fauna. This study is presented in the accompanying paper.

Elsewhere in the Cleveland area two Wisconsin tills, regarded as early Cary and late Cary, are frequently encountered and there is evidence in a few places of an earlier Wisconsin till believed to be Tazewell. In a road cut along the state road 1½ miles west of Strongsville, Illinoian till, the upper part leached and weathered, underlies calcareous late Cary Wisconsin drift. Newberry (1873, p. 177) and Coleman (1941, p. 69) have mentioned other localities near Cleveland where weathered drift below fresh drift or buried soil were exposed. The exposures are now covered, no details were published, and no loess has been previously noted. Leverett (1931, p. 60) states of post-Illinoian loess that "no exposures have been noted within the Cleveland district" but notes its occurrence "in southeastern Ohio." Leverett (1931, p. 65) interpreted the Mill Creek gravels, however, as subglacial deposits of Wisconsin age, apparently never having observed any buried soil horizon at their upper surface.

The Sangamon soil and overlying loesses are also exposed in ravines cut into the slopes of the large abandoned dredge pit of the Cleveland Builders Supply Company, adjacent on the west. At other pits, both east of McCracken Road and north of Broadway at Henry, the Wisconsin till rests directly upon fresh Illinoian gravel and there is no Sangamon soil, early Wisconsin loess, or lacustrine material. This is exactly the situation shown on the left side of figure 1. At the upper part of the large dredge pit at Henry two small pockets of leached gravel were exposed by stripping operations in 1951, but their explanation would be uncertain were not the more complete Sangamon sequence available elsewhere.

The lithologic character of the Illinoian gravel is quite distinct from that of Wisconsin tills and gravel (White, 1953). The buried Illinoian gravels of the county are known from three buried valleys and are favorable ground-water aquifers (Winslow, 1953).

At this time only tentative conclusions can be drawn about the age of the two loesses in this unusual occurrence. The gastropod fauna as determined by Leonard permits assignment of early Wisconsin age; this age is indicated also by the conformable position of the loesses above the Sangamon soil.

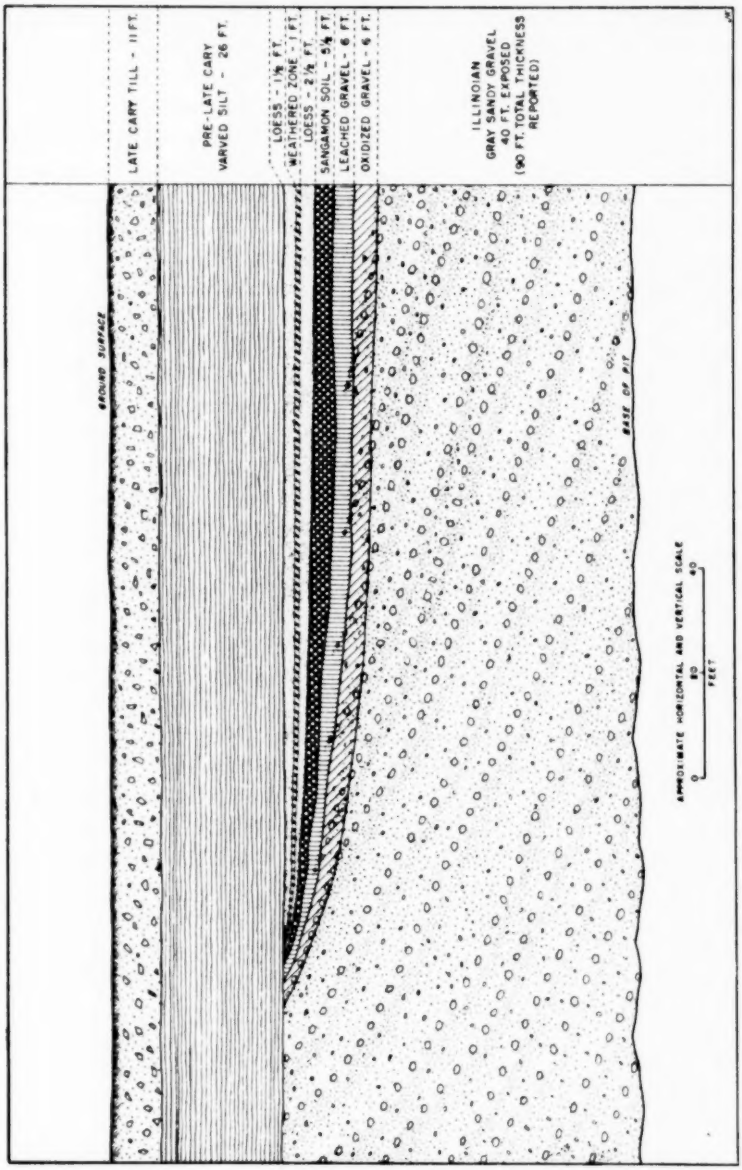

GROUND SURFACE
LATE CARY TILL - 11 FT.
PRE-LATE CARY VARVED SILT - 26 FT.
LOESS - 1½ FT.
WEATHERED ZONE - 1 FT.
LOESS - 2¼ FT.
SANGAMON SOIL - 5¼ FT.
LEACHED GRAVEL - 6 FT.
OXIDIZED GRAVEL - 6 FT.
ILLINOIAN GRAY SANDY GRAVEL 40 FT. EXPOSED (90 FT. TOTAL THICKNESS REPORTED)
BASE OF PIT
APPROXIMATE HORIZONTAL AND VERTICAL SCALE
0
80
40
FEET

Fig. 1. Section exposed in pit of Cleveland Sand and Gravel Company.

Two substages are indicated by the differences in fauna and by the weathered zone at the top of the lower loess. If both loesses are early Wisconsin the upper one most probably is early Tazewell (pro-Tazewell); the lower, pre-Tazewell. A very early Wisconsin ("pro-Wisconsin") loess which occurs in the Mississippi Valley, including Illinois and Indiana, has been named Farmdale by Leighton and Willman (1950, pp. 602, 613). As Iowan till has not been recognized east of the Mississippi River and as the basal early Wisconsin deposit closest to Cleveland is the Farmdale loess, the basal loess at Cleveland is, therefore, tentatively correlated as Farmdale. It should be noted that the lower loess here described resembles in appearance the Farmdale loess of Illinois. Accordingly, the strata exposed in the gravel pits record the following history:

1. Illinoian.—Deposition of gravel in the pre-Illinoian Mill Creek Valley. As the bedding is variable and the surface irregular the deposit is probably an Illinoian kame terrace.

2. Sangamon.—Weathering and soil formation. In a depression (kettlehole?) the water table stood near the surface and a heavy clay subsoil, practically a "gumbosand" (Leighton and MacClintock, 1930, p. 41), was formed. Pebbles in the ancient soil may be residual or may be colluvial, having been brought down from the higher slopes at the margin of the low area.

3. Wisconsin-*Farmdale* (?).—Just after Sangamon time fine material became available for wind transport and the lower loess was deposited. Perhaps, as is believed to have occurred in the Mississippi Valley (Leighton and Willman, 1950, p. 602), an early Wisconsin ice advance, to a position farther north than that reached by later ice advances, provided proglacial outwash from which wind-blown silt originated.

4. *post-Farmdale* (?).—A relatively short period of weathering and incipient soil formation accounts for the weathered zone at the top of the lower loess.

5. *pro-Tazewell* (?).—Proglacial outwash of a second early Wisconsin ice advance provided silt which was wind blown to form the upper loess. The gastropod fauna, studied by Leonard, permits a Tazewell correlation of this loess.

6. *pro-Tazewell* (?).—With the damming of drainage by the approach of the Tazewell ice, a glacial lake was formed in which the varved silt and clay was deposited. No appreciable time

intervened between the loess and the lacustrine deposits, because no weathered zone appears at the top of the upper loess. It should be noted that this early Wisconsin lake rose to an elevation above 910 feet, whereas a much later glacial Lake Maumee rose only to 812 feet (Leverett, 1931, p. 98).

7. *Tazewell.*—The Tazewell ice is not recorded by ice-laid deposits in this section although this ice covered Cuyahoga County. Tazewell till forms the surface material in central and southern Summit County, 20 miles south of Cleveland, and is known beneath Cary till from several outcrops in Cuyahoga County. It is not known whether its absence in this section is due to lack of deposition or to pre-Cary erosion.

8. *Cary.*—That the early Cary ice advanced far to the south of Cuyahoga County is shown by the early Cary age of the marginal Wisconsin drift of eastern Ohio (White, 1951, p. 976). There were two Cary advances, for a late Cary readvance after a marked retreat brought in a finer, more clayey till, which unconformably overlies coarser early Cary till at many places in Cuyahoga and adjacent counties. The till in the section here described, however, is all late Cary and no early Cary, coarse till is present, although two Cary tills are exposed in the upper part of a badly slumped pit ⅜ mile north.

9. *post-Cary.*—As the top of this section is above 812 feet elevation, the level of the highest stage of late glacial Lake Maumee, no record of any of the postglacial lakes is to be expected. The present soil has been formed from Late Cary to the present.

CONCLUSION

Illinoian drift is definitely identified and Sangamon soil is recorded in northeastern Ohio.

Loess was deposited during two episodes in early Wisconsin time. This is the first record of two loesses of this age in Ohio.

These materials, the Sangamon soil and the early Wisconsin loess, should now be looked for as horizon markers in subsurface Pleistocene stratigraphic studies in northern Ohio; if present, they will make possible more accurate correlation of drift sequences, especially of water-bearing gravels.

REFERENCES

Coleman, A. P., 1941. The last million years. A history of the Pleistocene in North America, G. F. Kay, editor, University of Toronto Press, Toronto.

Leighton, M. M., and MacClintock, Paul, 1930. Weathered zones of the drift sheets of Illinois: Jour. Geology, vol. 38, pp. 28-53.

————, and Willman, H. B., 1950. Loess formations of the Mississippi Valley: Jour. Geology, vol. 58, pp. 599-623.

Leverett, Frank, 1931. *In* Geology and mineral resources of the Cleveland District, Ohio: U. S. Geol. Survey Bull. 818.

Newberry, J. S., 1873. Report on the geology of Cuyahoga County: Ohio Geol. Survey, vol. 1, pp. 171-200.

Smith, W. H., 1949. Sand and gravel resources in northern Ohio: Ohio Geol. Survey Rept. Inv. 6.

White, G. W., 1951*a*. Illinoian and Wisconsin drift of the southern part of Grand River lobe: Geol. Soc. America Bull., vol. 62, pp. 967-977.

————, 1951*b*. Pleistocene stratigraphy in northeastern Ohio (abst.): Geol. Soc. America Bull., vol. 62, p. 1489.

————, 1953. Geology of the unconsolidated deposits of Cuyahoga County. *In* J. D. Winslow, 1953 (see below).

Winslow, J. D., 1953. The water resources of Cuyahoga County: Ohio Div. Water Bull. 26 (in press).

University of Illinois
Urbana, Illinois

[American Journal of Science, Vol. 251, May 1953, Pp. 369-376]

MOLLUSCAN FAUNULES IN WISCONSINAN LOESS AT CLEVELAND, OHIO

A. BYRON LEONARD

ABSTRACT. Two distinctive molluscan faunules occur in Wisconsinan loess exposed in a gravel pit near the southeast margin of the city of Cleveland, Ohio. One faunule, judged to be of early Wisconsinan age, and consisting of 16 species, occurs in loess immediately above Sangamon soil developed in Illinoian gravels; 9 of the 16 species are restricted to this loess. The second faunule, judged to be of Tazewellian age, and comprising 11 species, occurs in younger loess above a weathered zone and below varved clay; 4 of the 11 species are restricted to this faunule. Each of the 20 species of fossil mollusks in the total assemblage is illustrated by a photograph, and the vertical distribution of the several kinds is shown on a chart.

THE discovery of fossiliferous loess in northeastern Ohio is so unusual and so important to the study of Pleistocene stratigraphy in this region that the occurrence merits special attention. The molluscan faunules reported upon here were first observed by George W. White in loess exposed above gravels in a large shovel pit operation of the Cleveland Sand and Gravel Company, just southeast of Garfield Park at the southeast margin of the city of Cleveland, Ohio. Further details of the location and a description of the stratigraphic relations at the exposure are given in the accompanying paper by White, in company with whom samples of fossiliferous loess were collected for recovery and study of molluscan faunules.

At the time the samples were collected, the gravel pit exposed about five feet of loess above Sangamon soil developed in gravels of Illinoian age, and below varved silts underlying late Cary till. As shown in the measured section given by White, the upper one-third of the loess is light colored, calcareous and fossiliferous, while the lower two-thirds is dark colored, clayey, weathered and non-fossiliferous above, but weakly calcareous and somewhat fossiliferous in the lower part. Five bulk samples of the loess were taken: (1) from dark, humic-stained silt in what seemed to be the upper few inches of the Sangamon soil, (2) from the lower part of the lower loess (Farmdale? of White's measured section), (3) from the lower part of the upper loess (pro-Tazewell? of White), (4) from

this upper loess immediately below the varved silts, and (5) a channel sample. The occurrence of the various kinds of mollusks at the several levels sampled is shown in figure 1; each of the 20 kinds of mollusks comprising the aggregate molluscan assemblage now known from these loesses is shown in plate 1. The channel sample did not reveal kinds of mollusks not found in one or more of the other samples taken.

Terminology used in this paper distinguishes between time- or time-rock terms, for which adjectival endings are used (late Wisconsinan loess), and stratigraphic names, for which nouns are used (Farmdale loess).

It is obvious that the two loesses are distinguishable on the basis of their contained molluscan faunules (fig. 1). The assemblage in the lower (Farmdale? of White's measured section) loess contains 16 species of fossil mollusks (samples 1, 2), of which 9 are not found in the upper loess; the upper loess (White's pro-Tazewell?) contains 11 kinds of mollusks, of which 4 do not occur in the lower loess. Part of this difference is probably due to slightly different environments prevalent at the time of deposition of the two loesses, since the lower, unlike the upper, contains several aquatic species, *Gyraulus parvus, G. pattersoni, Helisoma antrosa, Lymnaea dalli grandis,* and *Menetus* sp. These aquatic species form an inconspicuous part of the faunal assemblage (each kind except *G. pattersoni* is represented in our collections by a single specimen) but their occurrence is indicative of a pond environment on the surface on which the loess was being deposited, at least at the beginning of the depositional period. The locally depressed topography at this time probably also accounts for the occurrence of a few shells in what seemed to be the upper few inches of Sangamon soil, where I judge that the shells were moved from higher ground by colluviation. Two observations support this view: (1) the shells in this zone are more often broken than those occurring elsewhere in the deposit; (2) the shells are not etched by weathering processes although they are imbedded in humic-stained, non-calcareous silt.

The characteristics of the faunal assemblage in the loess at Cleveland clearly attest to its early Wisconsinan age. *Columella alticola, Succinea avara gelida, S. grosvenori, Hendersonia occulta, Vertigo alpestris oughtoni, Gyraulus pattersoni, Lymnaea dalli grandis, Discus mcclintocki,* and perhaps

other species, are extinct in the region of northeastern Ohio. Such a high proportion of locally extinct species clearly indicates an early Wisconsinan age for the loesses in question and excludes an association of the loess with Cary till, for experience has shown that late Wisconsinan (post-Bradyan) deposits contain molluscan assemblages essentially like those living in the vicinity (Leonard, 1952, p. 16). Furthermore, the general character of the aggregate faunal assemblage is similar to that found elsewhere in early Wisconsinan loess, but the two faunal assemblages reported here do not correspond in detail with Iowan and Tazewellian faunal assemblages known to occur in early Wisconsinan loess in the Missouri Valley (Leonard, 1951, p. 325; 1952). *Discus patulus*, *Discus mcclintocki*, *Vertigo alpestris oughtoni*, *V. pygmaea*, *Carychium exile canadense*, and *Lymnaea dalli grandis* are not known to occur in early Wisconsinan molluscan faunas in the Missouri Valley, but each has its counterpart in a similar kind of snail. These and other details of difference between the upper and lower faunal assemblages in the Cleveland loess as compared with faunal assemblages in early Wisconsinan loess are easily accounted for by differences in soil, floral and climatic conditions in the two regions. It seems unwise at this time, in view of the lack of knowledge of molluscan faunal assemblages in Pleistocene deposits in northeastern Ohio, to attempt an exact correlation between the two distinctive faunal assemblages observed there and subdivisions of Wisconsinan time. All the facts available, however, tend to support the judgment of White concerning the age of the two loesses at the Cleveland exposure, but the confirmation cannot be a positive one, pending the acquisition of further knowledge of fossil molluscan faunas in Pleistocene deposits in northeastern Ohio.

THE MOLLUSCAN FAUNA

Aquatic Species

The aquatic species of mollusks found in these sediments are limited to the lower loess (fig. 1). They are all pulmonate gastropods and hence not restricted to permanent bodies of water. So far as known, each of these species lived in ponds or quiet streams and were capable of surviving periods without open water. The presence of these species in the lower loess

faunal assemblage indicates the presence of a pond here at least at the beginning of loess deposition.

Helisoma antrosa (Conrad), plate 1, i: This snail is re-

MOLLUSCAN SPECIES	SAMPLES			
	1	2	3	4
Columella alticola (INGERSOLL)			●	●
Discus patulus (DESHAYES)			●	●
Stenotrema leai (BINNEY)			●	●
Succinea avara gelida BAKER			●	●
Cionella lubrica (MULLER)	●	●	●	●
Euconulus fulvus (MULLER)	●	●	●	●
Hendersonia occulta (SAY)	●	●	●	●
Succinea grosvenori LEA	●	●	●	●
Pupilla muscorum (LINNE)	●	●	●	●
Vertigo alpestris oughtoni PILSBRY	●	●	●	●
Vertigo pygmaea (DRAPARNAUD)	●	●	●	●
Carychium exile canadense CLAPP		●		
Discus mc clintocki BAKER		●		
Gyraulus parvus (SAY)	●	●		
Gyraulus pattersoni BAKER	●	●		
Hawaiia minuscula (BINNEY)		●		
Helisoma antrosa (CONRAD)		●		
Lymnaea dalli grandis BAKER		●		
Menetus sp.		●		
Strobilops labyrinthica (SAY)		●		

Fig. 1. Occurrence and distribution of kinds of mollusks at levels sampled in loess at Cleveland exposure. 1. Species in four inches of colluvium(?) associated with Sangamon soil. 2. Species in lower loess (Farmdale?). 3. Species in lower part of pro-Tazewell loess. 4. Species in upper part of pro-Tazewell loess.

presented in our collections by a single individual. The species may be living in the vicinity; it is reported by Robertson and Blakeslee (1948, p. 65), from Chautauqua County, New York. It is a snail that lives in ponds and small streams.

Gyraulus parvus (Say), plate 1, h: Represented in our collections by two immature individuals. These shells may belong to the subspecies *urbanensis* described by Baker (1918, p. 94) from Pleistocene deposits on the campus of the University of Illinois.

Gyraulus pattersoni Baker, plate 1, g: The occurrence of this species in Wisconsinan deposits is unusual; Leonard (1950, p. 20) reports it only from sediments of Kansan age in the Great Plains region. This is also the first record for the species east of Harrison County, Iowa.

Menetus sp., plate 1, j: A single immature individual belonging to this genus is not certainly identifiable. Two species of *Menetus* are reported by Robertson and Blakeslee (1948, p. 71) from the Niagara region.

Lymnaea dalli grandis Baker, plate 1, o: This is a Pleistocene snail described by Baker (1930) in a discussion of the aquatic mollusks in Pleistocene sediments of Illinois. Robertson and Blakeslee (1948, p. 62) list it from Livingston County, New York, in the "outlet of marl swamp."

Terrestrial Species

Each of the species discussed here is a pulmonate gastropod, adapted to life on land. They require moist earth and plant debris in which to deposit their eggs and rear their young. All the species in this assemblage are discussed and illustrated by Pilsbry (1939-1948) and most of them are listed by Leonard (1950, 1952) from Pleistocene deposits in the Great Plains region.

Carychium exile canadense Clapp, plate 1, s: This snail, which was found only in the lower loess, lives near water, and might have been found around the margin of the ancient pond. Robertson and Blakeslee (1948, p. 50) report it from Ontario and Livingston counties, New York, and Oughton (1948, p. 78) reports it living as far north as James Bay, Ontario, Canada.

Cionella lubrica (Müller), plate 1, n: This woodland snail

very likely is living in the vicinity of Cleveland. It is common in Pleistocene deposits from the Kansan stage to the Recent.

Columella alticola (Ingersoll), plate 1, b: Found abundantly in the upper loess samples. Living colonies of this gastropod are limited to western montane regions (Leonard, 1952, fig. 13). In the Great Plains, this snail is found only in Pleistocene sediments of Tazewellian age.

Discus mcclintocki Baker, plate 1, p, q: This species is characteristic of Pleistocene sediments of Wisconsinan age, but a few living colonies have been found in Iowa.

Discus patulus (Deshayes), plate 1, l, m: This species may be living in the vicinity of Cleveland; it is reported by Robertson and Blakeslee (1948, p. 33) and Oughton (1948, p. 38) from the counties or provinces near lakes Erie and Ontario.

Neither of these species of *Discus* has been found in the western Missouri River Valley, where *Discus cronkhitei* and *D. shimeki* occur in Wisconsinan sediments (Leonard, 1952).

Euconulus fulvus (Müller), plate 1, f: This woodland snail is probably living in the vicinity of Cleveland, as it is reported by Robertson and Blakeslee (1948, p. 22) and by Oughton (1948, p. 18). It is a common fossil in deposits of Wisconsinan age in the Great Plains (Leonard, 1952, p. 19).

Hawaiia minuscula (Binney), plate 1, e: This ubiquitous little gastropod is known from sediments as old as Pliocene and it is found living almost everywhere in the United States.

Hendersonia occulta (Say), plate 1, r: This snail was described from Wisconsinan loess; a few colonies of living examples are known, but none in the vicinity of Cleveland. It is abundant in the Cleveland loess.

Pupilla muscorum (Linné), plate 1, a: This species is a common fossil in Wisconsinan deposits. It may be living in the vicinity of Cleveland, as it is reported from New York by Robertson and Blakeslee (1948, p. 40) and from Ontario, Canada, by Oughton (1948, p. 54).

Stenotrema leai (Binney), plate 1, t, u, v: This is a woodland species which probably is living in the vicinity of Cleveland.

Strobilops labyrinthica (Say), plate 1, k: Two examples of this woodland snail were found in the lower loess. It probably lives in the Cleveland area.

Succinea avara gelida Baker, plate 1, w: This small snail is known only from Pleistocene sediments of Wisconsinan age.

Succinea grosvenori Lea, plate 1, x: This species is extinct in the eastern part of the United States, although common in the loess at Cleveland and elsewhere, where loess faunas have been studied.

Vertigo alpestris oughtoni Pilsbry, plate 1, d: This tiny gastropod was described by Pilsbry (1948, p. 968) from living examples from Baffin Island, Northwest Territory, Canada. This is the first record from the United States. The colony on Baffin Island is the only record of living examples of this species.

Vertigo pygmaea (Draparnaud), plate 1, c: This minute snail was not reported by Robertson and Blakeslee (1948), but Oughton reports it from Southern Ontario (1948, p. 62). It is probably not living in the Cleveland area.

SUMMARY AND CONCLUSIONS

Two distinctive molluscan assemblages occur in loess near Cleveland, Ohio.

The lower molluscan assemblage is tentatively correlated with the Farmdale substage of Wisconsinan age, while the upper molluscan assemblage is tentatively correlated with the Tazewellian substage.

REFERENCES

Baker, F. C., 1918. Description of a new species and variety of Planorbis from post-glacial deposits: Nautilus, vol. 22, pp. 94-97.

———, 1930. A review of our present knowledge concerning the character and distribution of the Pleistocene aquatic molluscan life of Illinois: Illinois State Acad. Sci. Trans., vol. 22, pp. 411-434.

Leonard, A. B., 1950. A Yarmouthian molluscan fauna in the mid-continent region of the United States: Kansas Univ. Paleont. Contr. Mollusca, art. 3.

———, 1951. Stratigraphic zonation of the Peoria loess in Kansas: Jour. Geology, vol. 59, pp. 323-332.

———, 1952. Illinoian and Wisconsinan molluscan faunas in Kansas: Kansas Univ. Paleont. Contr. Mollusca, art. 4.

Oughton, John, 1948. A zoogeographical study of the land snails of Ontario: Univ. Toronto Studies, Biol. Ser., no. 57.

Pilsbry, H. A., 1939-1948. Land Mollusca of North America: Acad. Nat. Sci. Philadelphia Mon. 3, vol. 1, part 1, 1939; vol. 1, part 2, 1940; vol. 2, part 1, 1946; vol. 2, part 2, 1948.

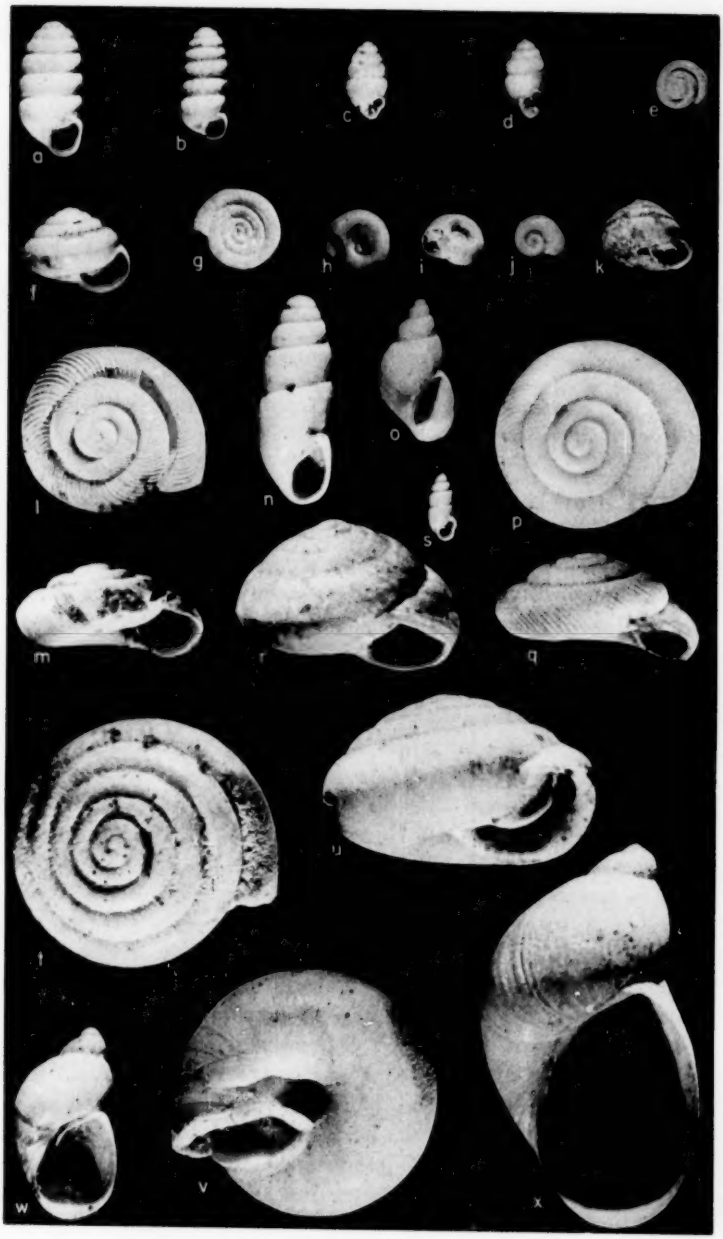
Robertson, I. C. S., and Blakeslee, C. L., 1948. The Mollusca of the Niagara Frontier Region: Buffalo Soc. Nat. Sci. Bull., vol. 19, no. 3.

PLATE 1

All figures enlarged 5 times.

a. *Pupilla muscorum* (Linné). Common.
b. *Columella alticola* (Ingersoll). Common.
c. *Vertigo pygmaea* (Draparnaud). Common.
d. *Vertigo alpestris oughtoni* Pilsbry. Common.
e. *Hawaiia minuscula* (Binney). Rare.
f. *Euconulus fulvus* (Müller). Rare.
g. *Gyraulus pattersoni* Baker. Immature, rare.
h. *Gyraulus parvus* (Say). Immature, rare.
i. *Helisoma antrosa* (Conrad). Immature, rare.
j. *Menetus* sp. Rare.
k. *Strobilops labyrinthica* (Say). Rare.
l., m. *Discus patulus* (Deshayes). Common.
n. *Cionella lubrica* (Müller). Common.
o. *Lymnaea dalli grandis* Baker. Rare.
p., q. *Discus mcclintocki* Baker. Common.
r. *Hendersonia occulta* (Say). Abundant.
s. *Carychium exile canadense* Clapp. Common.
t., u., v. *Stenotrema leai* (Binney). Common.
w. *Succinea avara gelida* Baker. Common.
x. *Succinea grosvenori* Lea. Common.

University of Kansas
Lawrence, Kansas


a
b
c
d
e
f
g
h
i
j
k
l
n
o
p
s
m
r
q
t
u
w
v
x

[American Journal of Science, Vol. 251, May 1953, Pp. 377-387]

THE USE OF ION EXCHANGE COLUMNS IN MINERAL ANALYSIS FOR AGE DETERMINATION

L. T. ALDRICH, J. B. DOAK, AND G. L. DAVIS

ABSTRACT. Ion exchange columns of synthetic organic resins have been found extremely useful in the routine separation of the alkali elements from those of the alkaline earths in the proportions in which they are found in potassium minerals. Complete separation of these groups of elements is essential for the mass spectrometric analysis of Ca and Sr in Rb-containing potassium minerals. Partial separations of Rb from K and Sr from Ca which increase the relative concentrations of Rb and Sr one hundred fold are made without difficulty. The use of suitable complexing agents for Fe and Al allow a high yield of Ca and Sr to be obtained from very small samples of iron aluminum silicate minerals.

THE ANALYTICAL PROBLEM

IN most mineral age determinations isotopic analysis of the daughter element is essential to determine the amount of this element resulting from the radioactive decay. The application of the techniques of isotope dilution described by Inghram, et al. (1950) for the quantitative determination of both parent and daughter elements in the mineral requires considerable chemical processing to extract these elements for mass spectrometric analysis. The problem involved in obtaining the material to be placed in the mass spectrometer is to separate from the mineral: (a) about 50 μg of Sr completely free from Rb and accompanied by not more than an equal amount of Ca; (b) about 50 μg of Rb accompanied by not much more than an equal amount of K. The need for these criteria arises from a consideration of the functioning of the mass spectrometer.

The source of ions is a heated ribbon of tungsten, plated with nickel to minimize chemical attack, on which has been dried a sample containing Sr (as chloride or carbonate) and the accompanying impurities. Sr^+ ions are emitted at about 1500°C. Any Rb present will be emitted as Rb^+ ions from the cooler parts of the filament; hence the contamination of Sr by Rb should be kept to an absolute minimum by employing the best possible separation procedures. If too much Ca is present, Ca^+ ions will constitute a major portion of the emission, there-

by distorting the isotope ratios being measured because of the saturation phenomena at the ion source.

In Rb isotope ratio determinations it has been found necessary to keep the amount of K impurity less than the amount of Rb so that Rb^+ constitutes at least one-half of the total ion current. Otherwise saturation effects may again distort the ion beam. Since the ratio K/Rb is about 100 in granitic rocks, at least 99 per cent of the K must be removed. It has been found that these separations may be conveniently effected by means of ion exchange resins.

COLUMN DESCRIPTION AND PREPARATION

The general properties of ion exchange columns for cation separation have been well summarized by Schubert (1949). Figure 1 is a schematic drawing showing the parts of and terminology used in describing column performance. The essential parameters of the column are listed with each of the separations shown and include the column volume, column

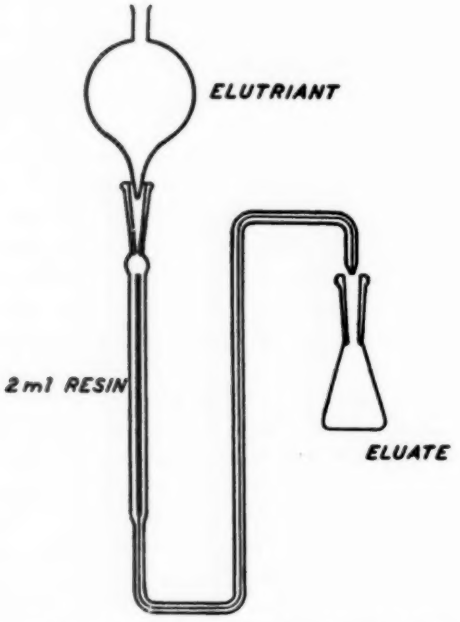


Fig. 1. Resin column with nomenclature used in this paper.

length, the resin used with its physical and chemical description, and the flow rate.

The columns were prepared by eluting with 10 column volumes of constant boiling point HCl (6.2N), then eluting with 2 column volumes and backwashing with 10 column volumes of distilled water. The backwashing completed the removal of the acid from the resin and left the column in an open form which allowed freer flow of elutriant. If the column was to be used in the H^+ form, it was now ready for the sample to be added. If the NH_4^+ form was desired, it was next eluted with a solution of NH_4Cl and NH_4OH at pH = 8-10, and the sample was added after backwashing with water to remove excess ammonia. The ammonia form of the column is useful in operations requiring a constant pH while cations are being removed from the solution containing the sample.

When the column is prepared, the sample is added in the appropriate form. For salts of the alkali and alkaline earth metals this form is a dilute solution in which the sum of the normalities is less than .05. After the sample has been added to the column, the elution with HCl of varying normality, depending on the separation desired, is begun. For standardization, fractions of the eluate were taken using an automatic drop-counting collector which gave equal volume samples. These could be analyzed by counting or with the flame photometer. In each case the behavior of the column was tested first with synthetic mineral samples made up from commercial chemicals and radioactive tracers. Subsequent separations with mineral samples showed the validity of this procedure. The separations shown have as abscissae column volumes of elutriant and as ordinates (except for K) counts/min/ml of eluate in arbitrary units depending on the activity of the tracer added. The analysis of K was made with a flame photometer. In both cases balance on amounts of material in the sample and amounts found in the collected fractions could be obtained by comparing with standards.

SEPARATIONS

We have to date studied separations in biotite and lepidolite, which have the generalized chemical compositions shown in table 1. These minerals have Rb-Sr ratios which have been shown by Mattauch (1937) and Ahrens and Whiting (1950)

to indicate that from 0.1 to 100 per cent of the Sr present is radiogenic. It has been found possible with the aid of ion exchange resins to obtain from these minerals Rb and Sr fractions separately, containing respectively not enough K and Ca to interfere with the determination of the isotope ratios. The size of sample required ranges from 0.1 to 2 g depending on the age and Rb content.

TABLE 1

Composition of Lepidolite and Biotite

Mineral	Li_2O	Na_2O	K_2O	Rb_2O	MgO	CaO	Fe_2O_3	Al_2O_3	SiO_2
Biotite	..	0.8	8.6	0.1	15	1.0	18	18	38
Lepidolite	5.0	0.1	10.0	1–2	..	..	0.4	27	50

Separation of alkalies.—Cohn and Kohn (1948) demonstrated the possibility of separating the alkali metals with columns. We have developed their procedure to make the separation faster and somewhat more complete.

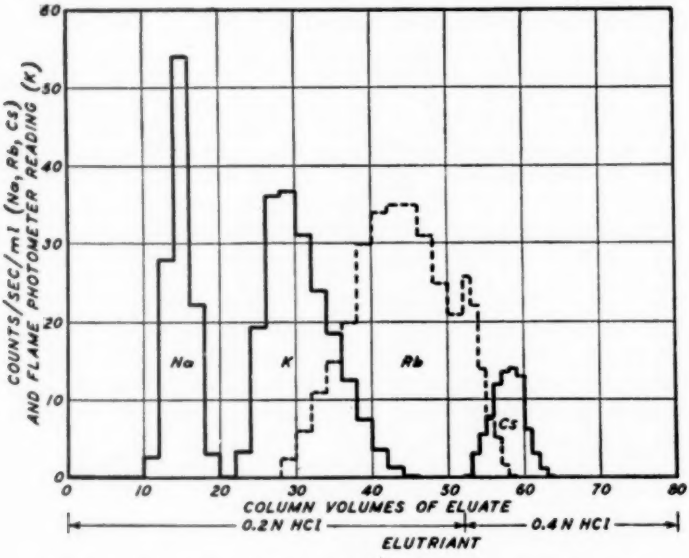


Fig. 2. Separation of Na, K, Rb, and Cs on Dowex 50 resin, 50-100 mesh, 8 per cent cross-linked.
Column volume = 6 ml Column length = 19 cm.

Figure 2 shows the separation of Na, K and Rb with two different normalities of HCl elutriant when the resin is Dowex 50, 8 per cent cross-linked, 50-100 mesh size. A fraction of eluate containing 65 per cent of the Rb and but 1 per cent of the K in the sample may be obtained. The Rb activity used contained some Cs activity which is the cause of the tail on the end of the Rb peak. A little more work would enable one to perfect the Rb-Cs separation. The K-Rb separation on 12 per cent cross-linked, 100-200 mesh Dowex 50 is shown in figure 3. This separation is somewhat better than that of figure 2 but takes longer because of the finer mesh size.

Alkali, alkaline earth separation.—Tompkins, Khym and Cohn (1947) reported a Sr-Ba separation using columns in the ammonia form and ammonium citrate solutions of varying pH as elutriants. We found their separation could be adapted to separate Ca and Sr; but if any alkali cations were present, they came out unpredictably and often mixed with the alkaline earth element of similar mass. We have, therefore, developed procedures to remove the alkalies from the column before Ca and Sr come out.

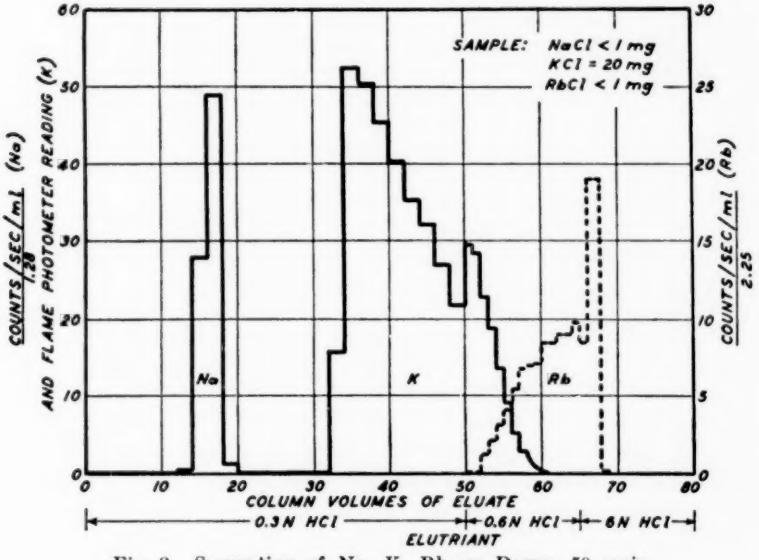


Fig. 3. Separation of Na, K, Rb on Dowex 50 resin, 100-200 mesh, 12 per cent cross-linked.
Column volume = 6 ml Column length = 19 cm.

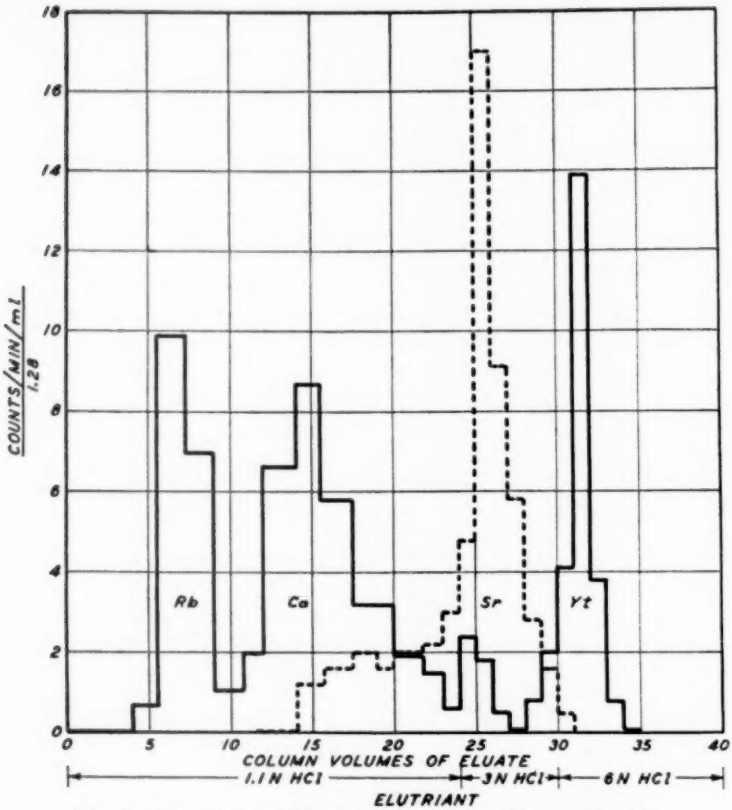


Fig. 4. Separation of Rb, Ca, Sr, and Y on Dowex 50 resin, 50-100 mesh, 8 per cent cross-linked.
Column volume = 2 ml Column length = 28 cm.

Figure 4 shows this separation as obtained with Dowex 50, 8 per cent cross-linked resin. HCl is used as elutriant. The Rb fraction is completely separated from the Ca-Sr fraction and the latter peaks are well resolved from each other. The separation of Sr and Y is seen to be essentially complete also. The Y present is that in equilibrium with the long-lived Sr used. This separation with carrier-free activity is itself of some interest. Figure 5 shows this same separation using Amberlite, IR-120, resin. The Rb-Ca separation is not quite as good in this case, but for practical purposes a sample of Sr free from Rb and most of the Ca can be easily and quickly obtained.

Two such Amberlite columns have been used for over 60 Sr separations during a 4-month period and their properties as checked with radioisotopes did not change during this num-

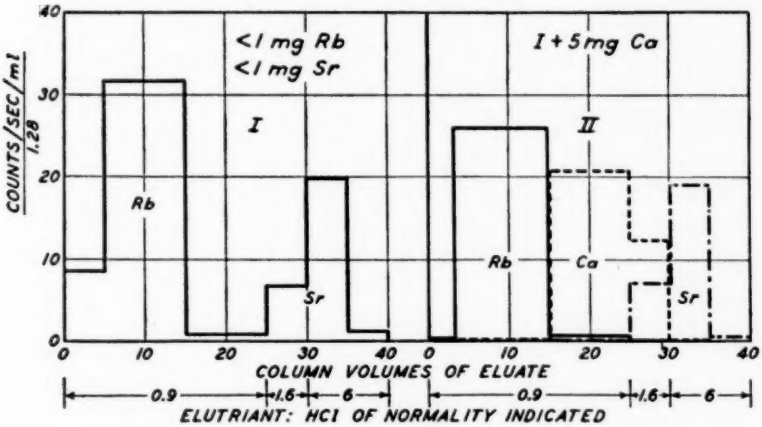


Fig. 5. Separation of Rb, Ca, and Sr, with Amberlite IR-120, 50 mesh resin.
Column volume = 2 ml Column length = 28 cm.
Flow rate = 4 column volumes/hour.

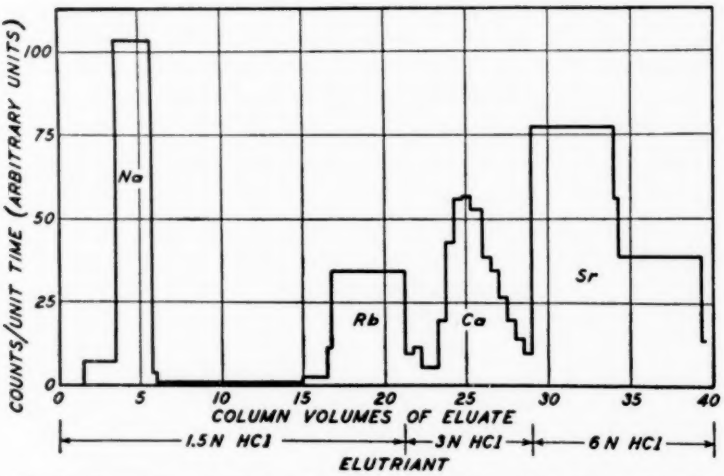


Fig. 6. Separation of alkali and alkaline earth elements on Dowex 50 resin, 100-200 mesh, 16 per cent cross-linked.
Column volume = 4 ml Column length = 19 cm.
Flow rate = 4 column volumes/hour.

ber of cycles. Figure 6 shows the same separation with Dowex 50, 16 per cent cross-linked, 100-200 mesh resin. The separation is better than on the 8 per cent 50-100 mesh, but it is seen that Sr is removed only with prolonged elution with 6.2N HCl. At this concentration HCl complexes many cations of higher valence, bringing them out with Sr. For these reasons the 50-100 mesh 8 per cent cross-linked Dowex 50 has been adopted for this work.

Contamination.—An experiment to check on contamination between successive samples run through the columns was performed as follows:

A sample of 1000 μg of reagent Sr was added to the Amberlite column and removed, using the procedure of figure 5. The column was prepared in the H^+ form. Then 100 μg of Sr[1] containing 64 per cent Sr^{84} was placed on the column and collected by the same procedure. The isotope ratios of the Sr so collected as measured on the mass spectrometer showed that less than 0.5 μg contamination of Sr of normal isotope distribution could have been contributed by the combined sources of column residual, eluting acid, and mass spectrometer evaporating ribbon. The column must therefore have contributed less than .05 per cent of the Sr from the previous run. Of the elements in which we are interested, Sr is the most difficult to remove from the column so we are confident that this represents an upper limit on carryover from one sample to the next in all our runs.

Extraction of alkalies and alkaline earths from Fe and Al silicates.—The difficulties in standard chemical procedures for concentrating Ca and Sr led us to look for column techniques. Reagents which complex elements normally cations into a form in which they are anions are known (Albert and Gledhill, 1947). It has been reported[2] that glycolic acid completely complexes Fe at pH 4 but leaves it as a cation at pH 1. We have found that Ca, Sr and the alkalies are not complexed by this reagent at pH 4.5; that is, more than 99 per cent of Rb, Ca and Sr present in such a solution is held up by a cation column. On the other hand more than 99 per cent of iron, aluminum,

[1] Obtained from the Stable Isotopes Branch, AEC, Oak Ridge, Tennessee.

[2] Technical Data, Amberlite IR-410, distributed by Rohm and Haas, Philadelphia, Pa.

and zirconium compounds complexed in this way passed through the cation column using Dowex 50, 50-100 mesh 16 per cent cross-linked resin.

ANALYTICAL PROCEDURE

Decomposition of the sample.—The weighed sample (100 mg of lepidolite or 1 g of biotite in small flakes) is placed in a 60 ml platinum evaporating dish, moistened with demineralized water, and an appropriate volume of "spike"[3] solution is added. About 5 ml each of redistilled 70 per cent perchloric acid and 48 per cent HF are added and the dish placed on a 100-120°C hotplate. Decomposition of the mineral proceeds smoothly and is usually complete within 3 hours. More of the acids may be added if necessary. The mineral should go completely into solution. The contents of the dish then are taken to dryness at 100°C.

Separation of the K, Rb perchlorates.—Ten ml of absolute ethyl alcohol are added to the dish and the contents stirred, with crushing of large aggregates. After 20 minutes the alcohol is decanted into a centrifuge tube. Two 5 ml washes of alcohol are usually sufficient. After centrifuging, the insoluble portions are collected, dissolved in water and taken to dryness. This portion contains the alkali perchlorates. The K and Rb can be separated with the H^+ form of an ion-exchange column as shown in figure 2, or, in the case of lepidolite, a single fractional crystallization from water will remove enough K so that a Rb determination may be made with the mass spectrometer.

Recovery of strontium.—The alcohol solution containing Li, Na, Al, Mg, Ca, Sr and Fe is diluted with two volumes of water and heated below boiling until the alcohol is removed. *If water is not added an explosion will occur when the solution becomes concentrated.* The solution is diluted to about 150 ml, twice the sample weight of glycolic acid is added, and the pH adjusted to 4.5 with NH_4OH. In this manner the Fe and Al are converted to complex anions which are not held on the cation-exchange resin. A 10 ml column of Dowex 50, 8 per cent cross-linked, 50-100 mesh resin in the ammonia form is washed

[3] The "spike" consists of Rb, Sr, or Ca with an abnormal isotope abundance and is added in order that the determination of these elements may be made on the mass spectrometer. See Inghram, et al. (1950).

with 1 per cent glycolic acid at pH 4.5 and the solution is passed through the column. A 50 ml wash with more of the glycolic solution follows.

The column is eluted with five column volumes of 0.5 N HCl and five column volumes of 3N HCl. The Sr is all contained in the 3N acid fraction. This fraction is dried, converted to the carbonate and placed on the ribbon of the mass spectrometer ion source for analysis.

DISCUSSION

Ion exchange columns have proved to be useful tools for separating concentrates of the alkali and alkaline earth metals from minerals when microgram quantities of these elements are available. The purity of the concentrates so obtained is sufficient to avoid difficulties of interference and source ion current saturation in the mass spectrometer. Further, it has been found that through the use of resin columns the concentrates themselves may be obtained with greater ease, higher yield and less chance of contamination than by conventional chemical procedures. The features of high yield and complete freedom from contamination indicate that these methods may be extended to improve the accuracy of any analysis for alkali and alkaline earth metals. Preliminary attempts at separations for this purpose have shown that this is probably the case. Further work on this use of the columns is in progress.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the inspiration for and continued interest in this work on the part of our colleagues P. H. Abelson and E. T. Bolton.

REFERENCES

Ahrens, L. H., and Whiting, F. B., 1950. Use of biotite for geological age measurements by the strontium method: Geol. Soc. America Bull., vol. 61, p. 1439.

Albert, A., and Gledhill, W. S., 1947. The choice of a chelating agent for inactivating trace metals: Biochem. Jour., vol. 41, pp. 529-545.

Cohn, W. E., and Kohn, H. W., 1948. Ion-exchange separation of the alkali metals: Am. Chemical Soc. Jour., vol. 70, p. 1986.

Inghram, M. G., Brown, H., Patterson, C., and Hess, D. C., 1950. The branching ratio of K^{40} radioactive decay: Phys. Rev., vol. 80, pp. 916-917.

Mattauch, J., 1937. The pair $Rb^{87}Sr^{87}$ and the isobar rule: Naturwiss., vol. 25, pp. 189-191.

Schubert, J. C., 1950. *In* Ion exchange: theory and application, F. C. Nachod, editor, Academic Press, New York. Pp. 167-222.

Tompkins, E. R., Khym, J. X., and Cohn, W. E., 1947. Ion exchange as a separation method: Am. Chemical Soc. Jour., vol. 69, pp. 2769-2777.

Department of Terrestrial Magnetism
and
Geophysical Laboratory
Carnegie Institution of Washington
Washington, D. C.

[American Journal of Science, Vol. 251, May 1953, Pp. 388-392]

COMMUNICATION

ORIGIN OF CHARNOCKITIC ASSEMBLAGES OF EAST MANBHUM, BIHAR.

REPORT has been made earlier of the occurrence of charnockitic assemblages of hypersthene-diopside-granulites showing transition to hypersthene granite, in East Manbhum, Bihar (86°30′ to 86°47′20″E; 24°27′45″ to 24°35′N; Sen 1951*a*, 1951*b*). The rocks resemble the charnockites in more than one respect and are strikingly similar to them in hand specimens. Thus besides the presence of the critical mineral hypersthene, such features as the occasional blue-gray color of the quartz in the quartz-bearing assemblages and associated pegmatites, a similar color occasionally also in feldspar, myrmekitic intergrowths between quartz and feldspar in the intermediate and the acid types, and a persistent xenomorphic granular texture are characteristic. These rocks are associated with amphibolites, calc-magnesian granulites, sillimanite-almandine (-graphite) schists and gneisses similar to khondalites of South India, leptynites, and a porphyritic granite.

Subsequent to the classical memoir of Holland (1900), several authors, among them Vredenberg (1918), Ghosh (1941) and Rama Rao (1945) in India, Stillwell (1918) and Tilley (1936, 1937) in Antarctica and Australia, Groves (1935) in South Africa, Ramberg (1948) in the Arctic, Hietanen (1947) and lately Quensel (1951) in Europe have made important contributions, advancing diverse suggestions regarding the origin of similar groups of rocks. It is intended here to put on record the conclusions reached by the author after a detailed study of the petrology and microtectonics of the area in Manbhum and to point out only the differences with the published suggestions.

In common with Ghosh the author ascribes the "differentiation" in the suite to a process of granitization that caused successive retrogression of the assemblages from the granulite facies to a granite, and in common with most of the later authors, including Rama Rao, he believes the rocks to be a complex series derived by repeated metamorphism of varied

rock types. Indeed the rocks have been found, as in the occurrence close to Baishkuli (86°32′45″E, 23°30′N)-Hariharpur (86°31′E, 23°29′30″N), to grade from an almost unreconstituted olivine metanorite. And again south of Ramchandrapur Hill (86°48′15″ to 86°49′25″E, 23°34′45″N approx.) and in the eastern extension of the area in the district of Bankura, they occur intimately associated with calc-magnesian metamorphites, often showing lateral passage. Field occurrences such as these prove beyond doubt that the pyroxene granulites are polyphyletic, connected genetically with the norite group of dike rocks on the one hand and with the calc-magnesian metamorphites on the other.

The mineral paragenesis of the pyroxene granulite and its associates, the khondalitic argillites and the calc-magnesian granulites (diopside-calc-granulites), together with the common occurrence of leptynites, indicate that they belong to the granulite facies. Unaffected by granites the assemblage of the hypersthene granulite is hypersthene-diopside-plagioclase. In the type assemblage hornblende is generally absent, or it occurs as thin rims round the pyroxenes. This assemblage (equivalent to the basic charnockites) has been variously influenced by granite, which has effected various degrees of granitization and produced ultimately a porphyritic granite, besides migmatitic composite gneisses, intermediate rocks of granodioritic to dioritic composition, and some hypersthene granite. In one occurrence near Baishkuli-Hariharpur, referred to above, a gradual set of changes is noticed, showing gradation successively outwards from olivine metanorite through pyroxene granulite to amphibolized pyroxene granulite, type amphibolite (rare), rocks of granodioritic composition, biotized migmatites, and finally hypersthene granite or hypersthene-free granite similar to the surrounding mass of the porphyritic granite.

In the olivine metanorite the feldspar shows teardrop inclusions of adjacent enstatite-hypersthene (or olivine), most of which have been converted into a strongly pleochroic fresh-looking hypersthene, similar to that of the granulites, and into diopside ($Z \wedge c\ 39°$ ca). The enstatitic hypersthene of the norites and the olivine metanorite shows a faint pleochroism under strong light, has characteristic schiller inclusions, with $2\ V_\gamma\ 79°30'$ on average (Fs_{23} Winchell, 1933). The hypersthene of the pyroxene granulites is distinctly different from the

enstatitic hypersthene and appears to be more ferriferous ($2V_\gamma$ 52°40′ to 53°30′; N_m 1.731 ± .003(Fs_{51} approx., Winchell, 1933). The evidence therefore points to the fact that this later hypersthene together with the diopside has been derived by reconstitution of the enstatitic hypersthene (and olivine) and the feldspar in the assemblage. The feldspar was acidified in the process (Sen, 1951*a*). The calc-diopside granulites (granulite facies equivalent of calc-magnesian metamorphites) and the related hypersthene-diopside-granulite have also been formed at the same time from portions originally different in composition and the two assemblages belong to the same facies. Their close association does not suggest derivation of one assemblage from the other. Hypersthene has never been found secondary after diopside and the diopside in both the assemblages has been simultaneously derived. Wide lateral variation in composition is very common in the calc-magnesian group and it is conceivable that hypersthene-diopside-granulite was derived from portions "comparatively rich in Fe and in FeMg over Ca" (Sen, 1951*a*). Since the progressive stages of metamorphism to the granulite facies are not represented in the area, the mineral reactions that yielded hypersthene in the sedimentary calc-magnesian assemblage remain obscure.

In summary, the metamorphic evolution is pictured as follows: All the rocks in the area, including sediments and intrusive basic dikes, were first metamorphosed at a very high grade (granulite facies), both the norite group and Fe-rich calc-magnesian sediments yielding hypersthene-diopside-granulite similar to the basic charnockites. Granitization, simultaneous with the later phase of the regional diastrophism and just postdating it, lowered the metamorphic grade of the assemblages gradually, forming hornblende at the expense of the pyroxenes, biotite at the expense of both the pyroxenes and the hornblende, together with a concomitant acidification of the plagioclase (incidental to the reaction and in later stages to the introduction of Na) and introduction of quartz and microcline. This process yielded successively some of the intermediate assemblages and finally granites, hypersthene-bearing (charnockites *sensu stricto*, rare) or hypersthene-free. The mineralogenetic trend pictured is indicated below, together with the trend suggested by Ghosh and Quensel.

Ghosh, P. K. (1941)

Diopside $\nearrow$ hypersthene $\searrow$ diopside → hornblende → bluish hornblende → biotite
$\searrow$ garnet $\nearrow$

Quensel, P. (1951)

Hornblende → diopside $\nearrow$ hypersthene $\searrow$ diopside → bluish hornblende → biotite
$\searrow$ garnet $\nearrow$

Sen, S. (1951)

Enstatite-hypersthene $\nearrow$ hypersthene $\searrow$ hornblende → bluish hornblende → biotite
$\searrow$ diopside $\nearrow$

(seen in relict norites)

The most important point of difference in the preferred petrogenetic history of the group with those of the other authors is the suggestion that the hypersthene-diopside-granulite (basic charnockite) is a result of metamorphic convergence, at high grade metamorphism, from noritic rocks and calc-magnesian sediments, and the assemblage is isofacial with the calc-diopside-granulite (in part). Though the subsequent trend is similar to Ghosh's, the emphasis is on the detail that the successive stages are the results of retrogression due to granitization, the granite being the end result of this process.

References

Ghosh, P. K., 1941. The charnockite series of Bastar State and western Jeypore: India Geol. Survey Rec., vol. 75, Prof. Paper 15.

Groves, A. W., 1935. The charnockite series of Uganda, British East Africa: Geol. Soc. London Quart. Jour., vol. 91, pp. 150-207.

Hietanen, Anna, 1947. Archaean geology of the Turku district in southwestern Finland: Geol. Soc. America Bull., vol. 58, pp. 1019-1084.

Holland, T. H., 1900. The charnockite series, a group of Archaean hypersthene rocks in peninsular India: India Geol. Survey Mem., vol. 28, part 2, pp. 119-249.

Quensel, P., 1951. The charnockite series of Varberg district on the southwestern coast of Sweden: Arkiv för Mineralogi och Geologi, Band 1, pp. 227-332.

Rama Rao, B., 1945. The charnockite rocks of Mysore: Mysore Geol. Dept. Bull. 18.

Ramberg, H., 1948. On the petrogenesis of the gneiss complex between Sukkertoppen and Christianshab, West Greenland: Dansk. geol. Fören. Medd., vol. 11: 3, pp. 314 ff.

Sen, S., 1951*a*. Petrology and structural petrology of the porphyritic granite and associated metamorphites of East Manbhum, Bihar. Thesis submitted for D.Sc. examination, 1951, Calcutta University (unpublished).

———, 1951*b*. Mineralogical and structural evolution of the metamorphites of East Manbhum, Bihar (abst.): Indian Sci. Cong. Proc., vol. 3, pp. 116-117.

Stillwell, F. L., 1918. The metamorphic rocks of Adelie Land: Australian Antarctic Expedition Rept., sec. A-3, part 1.

Tilley, C. E., 1936. Enderbite, a new member of the charnockite series: Geol. Mag., vol. 73, pp. 312-316.

———, 1937. Rocks from Enderby Land, Antarctica: B.A.N.Z. Antarctic Res. Exped. Rept., sec. A-2, part 1.

Vredenberg, E., 1918. Consideration regarding a possible relationship between the charnockites and the dharwars: Asiatic Soc. Bengal Jour., n.s., vol. 14, pp. 443-448.

CALCUTTA UNIVERSITY
CALCUTTA, INDIA

SAURINDRANATH SEN

REVIEWS

The Exact Sciences in Antiquity; by O. NEUGEBAUER. Pp. xvi, 191; 30 figs., 14 plates. Princeton, 1952 (Princeton University Press, $5.00).—The book is based on a course of six lectures delivered by the author at Cornell University in the fall of 1949. It presents a survey of mathematics and astronomy in ancient civilizations, principally those of Babylonia and Egypt, and an analysis of their relationships to Hellenistic science. Many of the results and conclusions presented are the fruits of the author's own labors, and have appeared previously only in the original technical publications.

Readers who have relied on textbook statements for information on the history of science will be shocked to find in how many instances traditional statements have been found to have no historical foundation. To give a few examples: mathematical texts of old-Babylonian times prove that the "Pythagorean" theorem was known more than a thousand years before Pythagoras; the legendary accuracy of Babylonian astronomical observations has been shown to be only a myth whose roots go back as far as the Hellenistic tradition about the "Babylonians" and "Chaldeans." Also the "Babylonian Saros" in the sense of a period of 223 synodic months fades away as a mistaken hypothesis, and with it the oft-repeated assertion that this period was used by Babylonians for the prediction of eclipses.

These examples are quoted at the risk of giving the impression that Professor Neugebauer's book is largely negative in content. Nothing could be further from the truth. The account of Babylonian and Egyptian mathematics and the discussion of the construction of ephemerides of the moon and planets in Babylonian astronomy of the Hellenistic period leave no doubt in the mind of the reader as to the vast amount of knowledge gained since the work of Epping and Strassmeier in the 1880's.

Throughout the book there exists an excellent balance between the presentation of the decipherment of problems and tables found on tablets or papyri and comments based on the author's experience with much more extensive material than could possibly be presented in some detail.

A chapter on "The sources; their decipherment and evaluation" contains many appalling statements on the unfortunate consequences of many Babylonian excavations that have destroyed beyond any hope all traces of the locality where the texts were found and on the loss of thousands of Babylonian tablets that were acquired at high cost by big and small collections but destroyed by inadequate preservation without ever having been read or recorded. Finally, the number of trained workers in this field is totally inadequate to cope with the vast amount of material that awaits decipherment.

The courageous presentation of facts and interpretations is bound to result in a wider interest in this fascinating and important field.

DIRK BROUWER

Johannes Kepler: Life and Letters; by CAROLA BAUMGARDT, with an introduction by Albert Einstein. Pp. 209. New York, 1951 (Philosophical Library, $3.75).—Carola Baumgardt writes on Kepler as a man rather than a scientist. She portrays with sympathy and understanding his life under religious persecution and financial hardship amidst the chaos of the Thirty Years War. Many selections are given from his correspondence from 1595 to 1630 with Mästlin, Galileo, Fabricius, Guldin, Schikard and others. Some of these letters have not previously been published. Kepler's contributions to astronomy are seldom made explicit in the biography itself, but his role as a giant is explained by Albert Einstein in his preface. The reader with a taste for the history of science will follow with much interest the account of Kepler's changing views on astrology. There are useful lists of Kepler's published works and of books on Kepler.

JOSEPH ASHBROOK

Astrophysics, A Topical Symposium Commemorating the Fiftieth Anniversary of the Yerkes Observatory and A Half Century of Progress in Astrophysics; J. A. HYNEK, Editor. Pp. xii, 703; numerous figs. New York, 1951 (McGraw-Hill Book Company, Inc., $12.00).—For this book fifteen authors have cooperated, reviewing the entire field of astrophysics. The contributions differ widely as to intent, scope and style, indicating that little pressure on the authors was exerted by the editor. This lack of uniformity may present some difficulties to students and workers in allied disciplines, looking here for up-to-date information on a subject whose literature is notoriously poor in books. This is definitely not a textbook, though some chapters have a strongly didactical flavor; for instance, Aller's on normal stellar spectra and Chandrasekhar's on stellar constitution. Other chapters are slanted historically. Especially interesting in Strömgren's account of the slow growth of theoretical astrophysics. Original research of outstanding importance is contained in Gerard P. Kuiper's contribution, entitled "On the Origin of the Solar System." This chapter systematically develops the author's cosmogonic ideas, which so far had been presented only in lectures and rather brief notes. The exposition is terse and largely mathematical, by no means easy reading. Characteristic of Kuiper's approach to the cosmogony of the solar system is the integration of the mechanical and chemical aspects of the problem. The latter are further developed in the monograph

reviewed below. Kuiper's theory marks a new departure in cosmogony and deserves the careful attention of everyone interested in the Earth Sciences. R. WILDT

The Atmosphere of the Earth and Planets, revised ed.; G. P. KUIPER, Editor. Pp. viii, 434; 16 plates, 90 figs. Chicago, 1952 (University of Chicago Press, $8.50).—The first edition of this book having been reviewed in this JOURNAL (1949, vol. 247, p. 584), it will suffice to draw attention to two major additions. Chapter 6 (The Spectra of the Night Sky and the Aurorae) has been revised jointly by its former author, Dr. P. Swings, and by Dr. A. B. Meinel, to whom we owe much of the rapid progress in this field since 1949. Chapter 12 (Planetary Atmospheres and Their Origin) has been greatly expanded by the editor. It should be studied in conjunction with Kuiper's theory of the origin of the solar system (see preceding review). This chapter also contains original investigations of the atmospheric heat balance in the Jovian planets and a fuller discussion of the surface features of Mars. R. WILDT

Modern Magnetism, 3rd ed.; by L. F. BATES. Pp. xii, 501; 134 figs. London and New York, 1951 (Cambridge University Press, $5.50).—In the first edition of this book the author broke custom with the usual strict theoretical treatments of magnetism and presented the subject principally from an experimental standpoint. In his third edition he has retained this emphasis and added much fresh material on fundamental experimental work of the last ten years, such as the application of high frequency techniques to paramagnetic and nuclear magnetic resonance. It is gratifying to receive this new up-to-date edition of a book which has been so useful to students and newcomers to research in magnetism. The description of experimental techniques and equipment for making magnetic measurements of all kinds, well illustrated with adequate reference to the literature, is particularly helpful. HENRY A. FAIRBANK

Chemische Analyse der Gesteine und Silikatischen Mineralien; by J. JAKOB. Pp. 180; 9 figs. Basel, 1952 (Verlag Birkhäuser, 18.70 Swiss francs).—This book is stated to be designed primarily as a laboratory manual for students, not a reference book. Hence selected methods are given, with little or no discussion of possible alternative methods.

That this book was written in 1949 and published in 1952 seems incredible. It contains 9 references to publications other than those by the author; of these, 5 are pre-1900, the others are to papers published in 1913, 1916, 1930, and 1931.

Although the book gives many valuable details of manipulative technique, it can not be recommended. Some of the procedures given are extremely long and tedious. For example, the method given for the R_2O_3 group requires 7 precipitations and the author gives no hint that the conventional method requires only two. Nor is any reason stated for not using the conventional procedure. Little or nothing is said of the importance of regulating pH in making precipitations (litmus paper is the only indicator mentioned!) or of the application of common ion effect in washing precipitates.

Many outmoded procedures are used, as, for example, the CaF_2 method for F and the bicarbonate separation of beryllium from aluminum. The expert may find valuable hints as to technique in this book, but it seems to me to be quite unsatisfactory and even dangerous for students' use. MICHAEL FLEISCHER

Illustrated Key to West North American Gastropod Genera; by A. Myra Keen and John C. Pearson. Pp. 40. Stanford, California, 1952 (Stanford University Press, $1.50).—This 40-page book will be welcomed by all malacologists and paleontologists as a valuable part of their working library. The key is based on shell characteristics only. It covers 240 west coast genera, and each is illustrated by a line drawing that brings out the diagnostic features of the shell with unusual clarity. In most cases the drawing was made over a photograph, then the image bleached away. There is an adequate glossary of terms, a plate showing the terminology used in describing the various parts of a gastropod shell, and alphabetical and systematic indices. This is a companion book to the *Illustrated Key to West North American Pelecypod Genera* by the senior author and Don L. Frizzell, published in 1939. Both are "musts" for anyone working in the molluscan field. P. A. MORRIS

Native Orchids of North America; by Donovan S. Correll. (New Series of Plant Science Books, Vol. 26.) Pp. xv, 399; 146 plates. Waltham, Mass., and New York, 1950 (Chronica Botanica Company, and Stechert-Hafner, Inc., $7.50).—This attractive volume presents the first complete treatment of the orchids of North America north of Mexico. Until the late Professor Oakes Ames became interested in the Orchidaceae more than half a century ago, the United States had no specialist in this fascinating group of plants. Over a period of many years, Dr. Ames assembled an unexcelled orchid herbarium and produced a long series of publications which were beautifully illustrated by his wife, Mrs. Blanche Ames.

The author of the volume under review was a former student and assistant of Professor Ames and received his early training in

orchidology in the Ames herbarium. For this reason, and because he has since maintained a keen interest in the Orchidaceae, he was singularly fitted to prepare this comprehensive work on the North American representatives of the group.

The volume includes full descriptions of 46 genera, 151 species, and a number of hybrids, varieties and forms. A key to the genera and keys to the species under each genus are also given. These keys are dichotomous, of the indented type, and the legs are numbered. The ease of using the keys is enhanced by the fact that a given pair of numbers is used only once in each key.

Following each technical generic description, the range of the genus and the number of included species are indicated, and in many cases additional notes are given. Each specific description is accompanied by a complete bibliographic reference to the accepted specific name and to the name-bringing synonym (if any). The more important synonyms also are listed, and in most cases the type locality and the type collections are cited. In addition the specific name is explained, and in most cases one or more common names are listed. The variation, habitat, range, and time of flowering of each species are likewise dealt with, and the geographical distribution is given in some detail. For most of the species there are cultural notes contributed by Edgar T. Wherry and J. V. Watkins and, in some cases, a record of the first successful introduction of the species into cultivation is added.

The descriptive portion of the book is followed by a glossary, a list of abbreviations of authors' names, a bibliography, and two indexes: one to scientific and the other to common names. The glossary is so complete that the amateur should have no difficulty using the book. Even such terms as *acid, bog, compound, evergreen, naked,* and *plateau* are defined. The list of abbreviations of authors gives the full names of each, his native country, and dates of his life. In using the index to common names one might reasonably expect to find listed those general names which have a generic connotation as: Lady's Slipper, Twayblade, Coral Root, etc. Actually these names do not appear as such and one must look under "c" for Clustered Lady's Slipper, "p" for Pink Lady's Slipper, "s" for Showy Lady's Slipper, etc. In the opinion of the reviewer, this system detracts from the usefulness of the index.

There remains yet to be mentioned one of the most attractive features of this well-written and organized volume. Each species is illustrated by attractive and scientifically accurate drawings. Except for 5 plates, all of these are the work of Mrs. Blanche Ames and Gordon W. Dillon. Mr. Dillon has followed so well the style of Mrs. Ames that in most cases their drawings can be distinguished only by the signatures. JOHN R. REEDER

Geography in the Making: The American Geographical Society, 1851-1951; by JOHN K. WRIGHT. Pp. xxi, 437; 20 figs., 30 plates. New York, 1952 (American Geographical Society, $5.00).—This handsome book is primarily a scholarly history of the American Geographical Society, pleasingly written by its former Director for the centennial celebration held in 1952. Some readers, expecting from the main title a history of modern geography, may be disappointed at finding so many details of the Society's past. It must be understood, however, that the Society, unlike many scientific associations that carry the word "American" in their titles, is not primarily a professional body. Most of its fellows and principal supporters are laymen, to whom the Society is of more central interest than the profession. And they may well be proud of their Society, which meets—one may even say sets—professional standards of research and publication. The professional geographers' society (the Association of American Geographers) was in fact once a foster child of the "A.G.S."

The patient reader will find that this book is by no means merely a "house history." A theme is stated (though not until page 175) that merits the attention of geographical theorists: "However abstrusely geographers may conceive the inner nature and the ideal purposes of their subject, its substance, in the form of actual investigations made, is closely responsive to current events in the larger world." This thesis is supported, as far as the American Geographical Society is concerned, by periods of interest in the Pacific railroad, the Isthmian canal, Arctic research, and conservation. One cannot always state whether the Society led or followed in the study of such problems, but certainly during the "Bowman era" and probably at other times, the Society was among the vanguard.

Aside from its value as historical record, the book is of interest in showing how a scientific society, supported mainly by laymen, disdaining popularization and mass membership, has been able to survive periods of adversity (from the latest of which it is now struggling to emerge) and grow in usefulness. Several unobtrusive chapters relate geography and the Society's activities to such broad topics as cartography and aviation. A minor but useful contribution is a key to the complicated series of publications that have borne the Society's name. STEPHEN B. JONES

PUBLICATIONS RECENTLY RECEIVED

U. S. Geological Survey Bulletins as follows: 948-D, Preliminary Report on the Bedded Manganese of the Lake Mead Region, Nevada and Arizona; by V. E. McKelvey, J. H. Wiese, and V. H. Johnson; 973-C, Dolomite Deposit near Sloan, Nevada; by Charles Deiss ($1.75); 973-D, Quicksilver Deposits in the Southern Pilot Mountains, Mineral County, Nevada; by D. A. Phoenix and J. B. Cathcart; 973-E, Quartz Crystal Deposits of Western Arkansas; by A. E. J. Engel ($1.50); 973-F, Fluorspar Deposits of Burro Mountains and Vicinity, New Mexico; by Elliot Gillerman ($1.50); 978-B, The Cle Elum River Nickeliferous Iron Deposits, Kittitas County, Washington; by C. A. Lamey and P. E. Hotz ($1.00); 978-D, Zinc-lead Deposit at Shawangunk Mine, Sullivan County, New York; by P. K. Sims and P. E. Hotz ($.60). U. S. Government Printing Office, Washington, 1952.

Acids and Bases, Their Quantitative Behaviour; by R. P. Bell. Methuen's Monographs on Chemical Subjects. London and New York, 1952 (Methuen & Co., Ltd., and John Wiley & Sons, Inc., $1.50).

Principles of Chemistry, 6th ed.; by J. H. Hildebrand and R. E. Powell. New York, 1952 (The Macmillan Company, $4.50).

Functional Anatomy of the Mammal, 2d ed.; by W. J. Leach. New York, 1952 (McGraw-Hill Book Company, Inc., $4.50).

Ultraviolet Radiation; by L. R. Koller. New York, 1952 (John Wiley & Sons, Inc., $6.50).

Geology and Ground-water Resources of the Kansas River Valley between Lawrence and Topeka, Kansas; by S. N. Davis and W. A. Carlson. Kansas Geological Survey Bulletin 96, Part 5, Lawrence, 1952.

Proceedings of the First Pan-African Congress on Prehistory; edited by L. S. B. Leakey, assisted by Sonia Cole. New York, 1952 (Philosophical Library, $8.75).

General Genetics; by A. M. Srb and R. D. Owen. San Francisco, 1952 (W. H. Freeman and Company, $5.50).

Biology, Its Human Implications, 2d ed.; by Garrett Hardin. San Francisco, 1952 (W. H. Freeman and Company, $5.00).

A Hundred Years of Biology; by Ben Dawes. London and New York, 1952 (Gerald Duckworth & Co., Ltd., and The Macmillan Company, $5.00).

Fluorspar, 4th ed.; by K. C. Dunham et al. Special Reports on the Mineral Resources of Great Britain, vol. IV. London, 1952 (His Majesty's Stationery Office, 17*s*, 6*d*).

An Explorer-scientist's Pilgrimage, the Autobiography of William Herbert Hobbs. Ann Arbor, Michigan (J. W. Edwards, Inc., $3.75).

Advanced Statistical Methods in Biometric Research; by C. R. Rao. New York, 1952 (John Wiley & Sons, Inc., $7.50).

Land Use and Soil Conservation; by A. T. Grove. Geological Survey of Nigeria Bulletin 22. Kaduna Junction, Nigeria, 1952.

Panorama of Science, 1952, compiled and edited by Webster Prentiss True. New York, 1952 (The Series Publishers, Inc.) Annual Supplement to the Smithsonian Series for 1952.

Illustrated Key to West North American Gastropod Genera; by A. Myra Keen and John C. Pearson. Stanford, California, 1952 (Stanford University Press, $1.50).

Metallurgy for Engineers: Casting, Welding, and Working; by John Wulff, Howard F. Taylor and Amos J. Shaler. New York and London, 1952 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $6.75).

Man Into Wolf; by Robert Eisler. New York, 1952 (Philosophical Library, $6.00).

Biochemical Preparations, Vol. 2; edited by Eric G. Ball. New York and London, 1952 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $3.00).

The Tree of Human History; by Alan H. Broderick. New York, 1952 (Philosophical Library, $4.75).

The Green Mountain Anticlinorium in the Vicinity of Rochester and East Middlebury, Vermont; by Philip H. Osberg. Vermont Geological Survey Bulletin 5. Montpelier, Vermont, 1952.

Man and the Biological World, 2d ed.; by J. Speed Rogers, Theodore H. Hubbell, and C. Francis Byers. New York, 1952 (McGraw-Hill Book Company, Inc., $5.75).

Sulphur and Pyrites in Canada; by T. H. Janes. Canada Dept. of Mines and Technical Surveys Memorandum Series no. 18. Ottawa, 1952.

Problems of Life; An Evaluation of Modern Biological Thought; by Ludwig von Bertalanffy. New York and London, 1952 (John Wiley & Sons, Inc., and Watts & Co., $4.00).

The Structure of Society; by Marion J. Levy, Jr. Princeton, New Jersey, 1952 (Princeton University Press, $5.00).

Detonation in Condensed Explosives; by J. Taylor. Oxford, England, 1952 (Oxford University Press, $5.00).

Quantitative Chemical Analysis, 10th ed.; by Leicester F. Hamilton and Stephen G. Simpson. New York, 1952 (The Macmillan Company, $4.50).

Semimicro Laboratory Exercises in General Chemistry, 2d ed.; by Burrows Arthur Smith. New York, 1952 (The Macmillan Company, $3.50).

Geology and Ground-water Resources of Lincoln County, Kansas; by Delmar W. Berry. State Geological Survey of Kansas Bulletin 95. Topeka, Kansas, 1952.

Radio Astronomy; by Bernard Lovell and J. A. Clegg. New York, 1952 (John Wiley & Sons, Inc., $4.00).

Man and Epidemics; by C.-E. A. Winslow. Princeton, New Jersey, 1952 (Princeton University Press, $4.00).

Thermochemical Methods in Silicate Investigations; by Wilhelm Eitel. New Brunswick, New Jersey, 1952 (Rutgers University Press, $4.75).

Practical and Experimental Geography; by W. G. V. Balchin and A. W. Richards. London and New York, 1952 (Methuen & Co., Ltd., and John Wiley & Sons, Inc., $2.75).

Hydrogen Ion Concentration; by John E. Ricco. Princeton, New Jersey, 1952 (Princeton University Press, $10.00).

Cambrian Stratigraphy and Paleontology near Caborca, Northwestern Sonora, Mexico; by G. Arthur Cooper and others. Washington, D. C., 1952 (Smithsonian Miscellaneous Collections, vol. 119, no. 1).

Études Américaines, Géologie et Géographie, Tome I; by Emm. de Margerie. Paris, 1952 (Librairie Armand Colin, paper bound).

The Epigenetics of Birds; by C. H. Waddington. New York, 1952 (Cambridge University Press, $7.00).

Theoretical Nuclear Physics; by J. M. Blatt and V. F. Weisskopf. New York and London, 1952 (John Wiley & Sons, and Chapman & Hall, Ltd., $12.50).

Vector Analysis; by E. C. Rex. Dubuque, Iowa (Wm. C. Brown Company, $3.25, paper bound).

Mechanics; by J. L. Meriam. Two vols., Part 1: Statics; Part 2: Dynamics. New York and London, 1952 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $4.00 each part).

PHILOSOPHICAL LIBRARY BOOKS

☐ **DEVELOPMENT OF THE GUIDED MISSILE** by Kenneth W. Gatland. This book presents factually all the main information now available on the development of guided weapons in Britain, the United States, Germany, the U.S.S.R. and elsewhere, and outlines their present and future possibilities.
A unique feature is the appendix showing the characteristics of all the more important powered missiles known to have been designed or constructed—a total of 90. Air Chief Marshal Sir Alec Coryton, former Chief Executive (Guided Weapons), Ministry of Supply, has contributed a foreword to this important book, and it is very fully illustrated. $3.75

☐ **INTERNAL BALLISTICS** by Colonel F.R.W. Hunt. An exhaustive treatise on research in that branch of applied physics relating to the properties of propellants and the motion of the projectile in the gun. $12.00

☐ **HARWELL—THE BRITISH ATOMIC ENERGY RESEARCH ESTABLISHMENT 1946-1951. Prepared by the Ministry of Supply and the Central Office of Information.** After giving a brief account of the events leading to the formation of the British Atomic Energy Research Establishment in 1946, and a review of its organization, there is an outline of the main tasks on which Harwell is working. These are treated under four heads: (1) the production program; (2) isotopes; (3) nuclear reactors, and (4) particle accelerators. $3.75

☐ **A HISTORY OF THE THEORIES OF AETHER AND ELECTRICITY** by Sir Edmund Whittaker. Sir Edmund Whittaker, FRS, Professor Emeritus of Mathematics in the University of Edinburgh, traces the 'classical' theories from the early Greeks up to the discoveries associated with such scientists as Ohm, Faraday, Maxwell and Lorentz. Volume One is subtitled **The Classical Theories.** $8.75

☐ **OUT OF MY LATER YEARS** by Albert Einstein. The distinguished physicist, always an independent and uncompromising thinker, deals with the most urgent questions of modern society: Social, religious, educational, and racial relationships. Various sections deal with personal credos, politics, education, the Jewish issue, war and peace, the fundamental principles of physics. In several chapters the author explains his theory of relativity in such simple terms as to be understood by every intelligent person. The book shows Einstein the philosopher, Einstein the scientist, and Einstein the man. It is a treasury of living thought and a striking record of one of our most eminent contemporaries. $4.75

☐ **DEAD CITIES AND FORGOTTEN TRIBES** by Gordon Cooper. In this book Gordon Cooper traces the history of vanished peoples, their rulers and their fate: he tells too, of some of the least known races of the world, like the Lepches of Sikkim and the Jivaros of Peru, and the strange people of the Lost Valley in the Loranje Mountains in New Guinea, who were discovered by the crew of an American plane making an emergency landing during the war. $4.75

☐ **THE STORY OF WATCHES** by T. P. Camerer Cuss. **Fellow of the British Horological Institute and President of the National Association of Goldsmiths.** The story of the watch from its origin in the portable clocks of the fifteenth century down to the factory-made watch of today, tracing its development in all its aspects. $7.50

☐ **WATER** by Sir Cyril S. Fox, D.Sc., F.G.S. It is the intention, in this volume, to provide the reader with an outline of the Science of Water, both in the academic and practical aspects of the subject and to include details regarding its characteristics, its occurrence and its utilization. **Illustrated** $8.75

☐ **THE NEW PHYSICS: TALKS ON ASPECTS OF SCIENCE** by Sir C. V. Raman. These talks by the world-renowned Indian physicist, a Nobel Prize winner, open new fields of beauty in the things of nature. $3.75

☐ **REFLECTIONS OF A PHYSICIST** by P. W. Bridgman. This work includes most of the non-technical writings of Dr. Bridgman and the topics include a discussion of the problems created by the increasingly important social role science is coming to play. $5.00

☐ **BORDERLANDS OF SCIENCE** by Alfred Still. The author discusses the contributions of science to the distinguishing of reason from belief and deals with phenomena for which the scientist has failed to provide a reasonable explanation. He explores the phenomena of the divining rod; levitation; poltergeist evidence and telekinesis; body, mind, and memory; the subconscious; instinct, intuition, and genius; automatic writing; hypnotism and clairvoyance; psychometry and telepathy. Will fascinate scientists and layman alike. **Bibliography.** $3.75

☐ **A CONCISE HISTORY OF ASTRONOMY** by Peter Doig, F.R.A.S. A new volume which provides a comprehensive and concise account of the development of Astronomy from earliest times to the present. $4.75

☐ **DICTIONARY OF SCIENCE AND TECHNOLOGY** by Maxim Newmark. **In English—French—German—Spanish. Three Bilingual Dictionaries in One.** More than 10,000 current English terms most frequently used in the physical sciences and mathematics are given, each with its French, German, and Spanish equivalents. $6.00

☐ **POCKET ENCYCLOPEDIA OF ATOMIC ENERGY** by Frank Gaynor. More than 2,000 entries defining and explaining concepts and terms in nuclear physics and atomic energy makes this volume a vital handbook for all those concerned with atomic science. **Illustrations, charts, tables.** $7.50

☐ **JOHANNES KEPLER: LIFE AND LETTERS** by Carola Baumgardt. **With an introduction by Albert Einstein.** This is the first biography of the father of modern astronomy to employ the voluminous correspondence which Kepler conducted with the royalty of Europe and the leading scholars and laymen of his time. **Illustrations include facsimiles of manuscripts by Kepler.** $3.75

☐ **GEOGRAPHY IN THE TWENTIETH CENTURY** by Griffith Taylor. Twenty specialists explore the growth, fields, techniques, aims, and trends of modern geography. **Glossary and more than 50 text figures.** $8.75

☐ **THE DICTIONARY OF PHILOSOPHY.** Dagobert D. Runes, Editor. This compact handy volume, all-embracing in content, clear in exposition, objective in viewpoint and authoritative, is invaluable for the teacher, the student, or the layman. $6.00

☐ **THE COMPOSITION AND ASSAYING OF MINERALS** by John Stewart-Remington and Dr. Wilfrid Francis. The volume relates primarily to the chemical composition of minerals, with the object of providing a handy guide to their qualitative and quantitative examination that is suitable for use by mineralogists, metallurgists, geologists, chemists in mine laboratories, and students in schools, technical colleges, and universities. $5.50

MAIL THIS COUPON TODAY

PHILOSOPHICAL LIBRARY, Publishers
15 East 40th Street, Desk 644, New York 16, N. Y.

Send books checked. To expedite shipment I enclose remittance $.....

NAME .....

ADDRESS .....

.....

ELECTROMETERS

Wulf Uni and Bifilar Models

Vacuum Duant and Other Types

One and Two Circle Reflection Goniometers

PULFRICH REFRACTOMETERS — INTERFEROMETERS

Write for Literature to

C. A. Brinkmann & Co.

378-380 Great Neck Road Great Neck, L. I., N. Y.

Announcing

SPECIAL STUDENT SUBSCRIPTION RATE

THE AMERICAN JOURNAL OF SCIENCE

Devoted to the Geological Sciences and to related fields

Editors: CHESTER R. LONGWELL, JOHN RODGERS

12 issues per year

Regular subscription rate, $8.00; student rate, $5.00

(Postage prepaid to the United States, The Philippines, and Central and South America; 35c a year to Canada; 60c elsewhere).

Special student application blanks furnished on request to:

The American Journal of Science, 501 Sterling Tower, New Haven, Connecticut

VOL. 251 No. 5, 1953

CONTENTS

ORIGIN OF ALASKA SILTS ..... *Stephen Taber* 321

THE SYSTEM MgO—Al_2O_3—H_2O AND INFLUENCE OF CARBONATE AND NITRATE IONS ON THE PHASE EQUILIBRIA
Della M. Roy, Rustum Roy, and E. F. Osborn 337

SANGAMON SOIL AND EARLY WISCONSIN LOESSES AT CLEVELAND, OHIO ..... *George W. White* 362

MOLLUSCAN FAUNULES IN WISCONSINAN LOESS AT CLEVELAND, OHIO ..... *A. Byron Leonard* 369

THE USE OF ION EXCHANGE COLUMNS IN MINERAL ANALYSIS FOR AGE DETERMINATION
L. T. Aldrich, J. B. Doak, and G. L. Davis 377

COMMUNICATION

Origin of Charnockitic Assemblages of East Manbhum, Bihar
Saurindranath Sen 388

REVIEWS

The Exact Sciences in Antiquity; by O. NEUGEBAUER ..... *Dirk Brouwer* 393

Johannes Kepler: Life and Letters; by CAROLA BAUMGARDT
Joseph Ashbrook 394

Astrophysics, A Topical Symposium; J. A. HYNEK, Editor ..... *R. Wildt* 394

The Atmosphere of the Earth and Planets, revised ed.; G. P. KUIPER, Editor
R. Wildt 395

Modern Magnetism, 3rd ed.; by L. F. BATES ..... *Henry A. Fairbank* 395

Chemische Analyse der Gesteine und Silikatischen Mineralien; by J. JAKOB
Michael Fleischer 395

Illustrated Key to West North American Gastropod Genera; by A. MYRA KEEN and JOHN C. PEARSON ..... *P. A. Morris* 396

Native Orchids of North America; by DONOVAN S. CORRELL
John R. Reeder 396

Geography in the Making: The American Geographical Society, 1851-1951; by JOHN K. WRIGHT ..... *Stephen B. Jones* 398

PUBLICATIONS RECENTLY RECEIVED 399

PAYNE & LANE, *Printers* — NEW HAVEN, CONN.